||| 1.0

4.5
5.0
5.6
||| 2.8 ||| 2.5

||| 3.2 ||| 2.2

3.6

4.0 ||| 2.0

||| 1.1

||| 1.8

||| 1.25 ||| 1.4 ||| 1.6
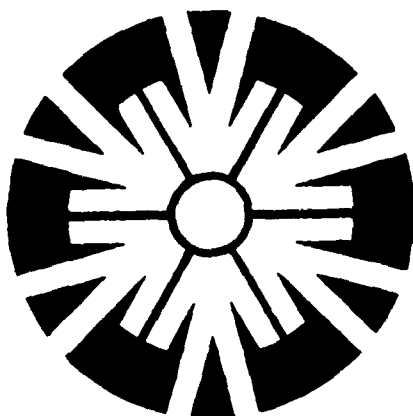
MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963-A

LEVEL

AD A092313

REVIEW OF THE STRENGTH AND CAPACITY DATA
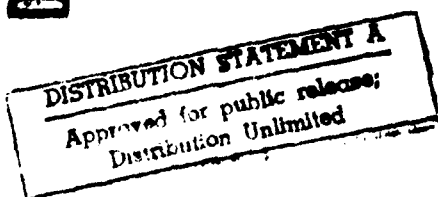
FOR MANUAL MATERIAL HANDLING ACTIVITIES

M. M. Ayoub

N. J. Bethea

S. Asfour

G. Calisto

C. Grasley

Institute for Biotechnology

TEXAS TECH UNIVERSITY

Lubbock, Texas 79409

November, 1979

80 11 25 038

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD A092313	3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle) REVIEW OF THE STRENGTH AND CAPACITY DATA FOR MANUAL MATERIAL HANDLING ACTIVITIES.	5. TYPE OF REPORT & PERIOD COVERED Final Report. May 77 - Nov 79.
	6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s) M.M. Ayoub G. Calisto N.J. Bethea C. Grasley S. Asfour	8. CONTRACT OR GRANT NUMBER(s) N63126-77-M-1719

9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute for Biotechnology Texas Tech University Lubbock, TX 79409	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS Pacific Missile Test Center Point Mugu, CA	12. REPORT DATE November 79
	13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

manual material	handling activities	psychophysical MIL-STD-1472B
lifting	pulling	biomechanical
lowering	strength norms	models
carrying	capacity norms	static strength
pushing	physiological	dynamic strength

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the results of activities to review the strength and capacity data for Manual Material Handling Activities (MMHA). These efforts primarily involved a review of MMHA literature, preparation of an annotated bibliography and a summary of literature findings. To supplement these findings, experimental data were collected on the effect of the location of the center of gravity of the load and the effects of the presence or absence of couplings on the amount of weight lifted. The results from both of

DD FORM 1473 (JAN 73)

20. Continued

the research efforts and the literature review were used to formulate recommendations for the revision of Military Standard 1472B for MMHA.

A brief summary of the results found for lift/lower, push/pull and carry activities is provided in the text.

Accession For	
NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
	Avail and/or
Dist	Special
A	

SUMMARY

This report describes the results of activities to review the strength and capacity data for Manual Material Handling Activities (MMHA). These efforts primarily involved a review of MMHA literature, preparation of an annotated bibliography and a summary of literature findings. To supplement these findings, experimental data were collected on the effect of the location of the center of gravity of the load and the effect of the presence or absence of couplings on the amount of weight lifted. The results from both of the research efforts and the literature review were used to formulate recommendations for the revision of Military Standard 1472B for MMHA.

A brief summary of the results found for lift/lower, push/pull, and carry activities is given below.

Lifting and Lowering

It has been generally found that the maximum acceptable weight of a load tends to decrease as the height of lift increases. The greatest maximum acceptable weight is usually found in the floor to knuckle height range with a consequent decrease in the acceptable weight as the height of lift ranges from knuckle to shoulder and from floor to shoulder heights. In addition, the amount of weight lifted is also a function of the rate of lift; as the frequency of lift (lifts/min) increases, the maximum acceptable weight decreases.

The dimensions of a load (i.e., length and width) have also been shown to affect lifting capacity. Generally, research has shown that as the object length (i.e., distance of the object's center of gravity [C.G.] from the carrier's body) is increased, while maintaining the load constant, the nature of the lifting task becomes more demanding. Data show that the ability to lift is reduced when the C.G. of the load is moved away from the carrier's spine in the sagittal plane. Object width (i.e., distance between hands) has also been shown to have little effect on the demands of the lifting task.

The presence or absence of handles on boxes has been

1

shown to have an additional effect on the amount of weight lifted; equipping boxes with handles usually allows for approximately 15% greater lifting capability.

When comparing the lifting capabilities of both male and female employees, it was found that females had a lifting capability of approximately 65 percent of the males lifting capability.

Pushing and Pulling

Research dealing with the effects of body posture on sustained pushing and pulling forces has shown that a change in body position, control placement, or body stabilization would reduce the required effort to maintain a given force under control. For example, a greater pulling force is usually generated from a sitting, rather than a standing position. Further, an increase in the knee and elbow angles gives similar results. The isometric pushing and pulling forces also vary as a function of the interaction between a subject's body weight, foot, and hand placements (foot placement is the distance of rear foot from vertical plane; hand placement is based on the height of the handle from the floor). For example, stronger pushing forces are usually found with higher hand placements and larger foot distances, while stronger pulling forces are generally generated by smaller foot distances and lower hand placements.

When examining the pushing and pulling capabilities for males and females, it is commonly found that the initial force (lbs) is greater than the sustained force. In addition, the generated initial force seems to depend on whether the rate of work is low, intermediate, or high; a higher initial force is found at low work rates than at intermediate or high work rates.

Carrying

The data generally reveal that an increase in carrying distance results in a decrease of the maximum acceptable weight when carrying a tote box at elbow height. When examining

the maximum work loads (ft.-lb./min.) acceptable to male and female workers while carrying a tote box at elbow height, an opposite trend was found; an increase in carrying distance results in an increase of acceptable work loads for the male and female workers.

A comparison of the maximum acceptable weights for males and females while carrying a 19 x 13.5 x 5.5 inch tote box at elbow height revealed that the acceptable weight for females was approximately 75 percent of the acceptable weight for males.

TABLE OF CONTENTS

List of Figures

List of Tables

INTRODUCTION

Poulson (1970) pointed out that the "rules for what workers handle manually vary widely from country to country, and the way in which these rules have been laid down very often depends on national laws and tradition."

It is now recognized that regulations for manual materials handling activities (MMHA) must be based on known human limits [Jones, 1971, 1972; Brown, 1971; Snook and Ciriello, 1972]. The selection of such limits is difficult, however, because of the variations in the operating conditions of the Man-Task-Environment System, namely, worker variables, task variables, and environmental variables.

OBJECTIVES

The objectives of this project were:
1. to review the current MMHA literature and prepare an annotated bibliography,
2. to conduct small experiments, to provide additionally needed data pertinent to MMHA, and
3. to provide data summaries to be used in updating standards to reflect the current state of the art in the manual material handling strengths and capacities.

To meet these objectives, the scientific literature was searched to determine the amount and quality of existing research on capacity and strength in MMHA. Relevant articles were abstracted. The information obtained from them was then classified into one of three categories depending upon the type of activity described in the article. These categories were:
1. lifting and lowering,
2. pushing and pulling, and
3. carrying.

These literature survey efforts identified MMHA that have not been adequately researched. Therefore, experimental data were collected on the effects of the presence of handles

and the location of the center of gravity on lifting activities.

Summaries of all available literature in each group were then prepared for use in updating MIL-STD-1472B.

METHODS

LITERATURE SEARCH

In the search for information on capacity and strength in manual materials handling activities (MMHA), the reviewers contacted as many sources as possible to make sure that reports of limited distribution, as well as reports in the published literature were included. The Texas Tech University library and the Texas Tech School of Medicine libraries were used for periodical holdings, cataloging systems, reference area containing abstract and bibliographic sources, and sources of referral to other libraries and institutions containing pertinent information through the interlibrary loan system. Computer data base facilities were assessed for their possible usefulness in the information search. To identify specific references of possible interest, four computer searches were actually used. They were:

1. American Psychological Association, Computer Search of Psychological Abstracts,

2. Medline, off-line Bibliographic Citation of the National Library of Medicine,

3. National Technical Information Service, U.S. Department of Commerce, and

4. Biosis, Computer Search of Biological Abstracts.

The Computer Search was supplemented by a manual search of abstract sources. Among those examined were:

1. Occupational Safety and Health Abstracts,

2. Dissertation Abstracts,

3. Engineering Abstracts, and

4. Index Medicus.

The various search procedures used to identify appropriate literature may generally be characterized as yielding three types of materials. These were:

1. titles, usually obtained from computer searches or referrals from other sources,

2. abstracts, (which of course included titles) usually resulting from the search of periodical abstract listings, and

3. documents, reprints of actual articles, books, reviews obtained by library search or by referral.

When only titles were obtained as from a computer search or referral from another source, the title generally indicated whether the reference was appropriate or not. If the title indicated that the article was inappropriate, it was eliminated from further consideration. When titles appeared promising, the document was obtained, reviewed, and relevant articles were abstracted. Frequently, references were mentioned in an article. If these were of importance to the objectives, they were obtained and abstracted (Appendix).

EXPERIMENTAL PROCEDURES

To achieve the second objective of this project, providing additionally needed data pertinent to MMHA, two laboratory experiments were conducted. Lifting capacity data were generated at Texas Tech University's Department of Industrial Engineering Laboratory. Conducting these two experiments helped in studying the effects of frequency of lift, height and range of lift, box size, location of the center of gravity (C.G.) of the load, and the effect of equipping the loads with handles on the lifting capacity of the individuals. In the two experiments a modified psychophysical technique was used.

Psychophysics is a very old branch of physiology that is concerned with the relationship between sensations and their physical stimuli; very rarely is this a one-to-one relationship. Stevens (1975) indicated that the strength of a sensation (S) is directly related to the intensity of

its physical stimulus (I) by means of a power function:

$$S = kI^n$$

where

S = strength of a sensation

I = intensity of physical stimulus

k = a constant which is a function of the particular units of measurement that are used

n = the slope of the line that represents the power function when plotting in log-log coordinates. It is equal to 3.5 for electric shock, and 1.6 for the perception of muscular effort and force.

The modified psychophysical technique used in these experiments allowed the subject to subjectively, (i.e., based upon his estimate of his working capacity, fatigue, and endurance) adjust the amount of weight he could lift repetitively for an 8 hour work day. The subject was instructed to adjust his work load to the maximum amount that he could perform, without strain or discomfort and without becoming tired, weakened, overheated, or out of breath.

Experiment (I): Unbalanced Load

Experimental Variables

There are three categories of variables that can influence the lifting capacity data values. These are: (1) worker variables, (2) task variables, and (3) environmental variables.

1. Worker Variables

The subjects participating in this project were four students with no experience in manual materials handling. All subjects were males. No attempt was made either to change or standardize each subject's method of lift; i.e., the subjects were allowed to use their "free style" lifting technique.

2. Task Variables

Frequency to Lift. The frequency of lift for

each task consisted of one of two levels utilized in the experiment. These were 2 and 6 lifts per minute. These frequencies were chosen to cover the range of frequencies encountered in industry. The subjects were paced in order to maintain the assigned lifting frequency for the duration of that particular lifting task combination.

Height and Vertical Range of Lift. The vertical range of lift consisted of three levels, each with a specific starting and terminating point. The combinations are given in Table 1.

Location of the Center of Gravity of Load Lifted. Two locations of the C.G. of load lifted were utilized:

  a. The C.G. of load lifted coincided with the geometri-
      cal C.G. of the box used, and
  b. the C.G. of the load shifted 4 in. in the direction
      of the non-preferred or weaker arm. The shift was
      in the frontal plane.

The box used had a size of 12 in. x 12 in. x 7 in. (width x length x depth).

3. Environmental Variables

Environmental Variables (e.g., humidity, temperature illumination) were not varied, but rather they were maintained within normal ranges throughout the experimental phase (72°F-74°F room temperature held constant).

The Task:

The lifting task required the use of a lifting apparatus, a container with handles, and lead weights. Each lifting task was comprised of one level of each of the task variables (frequency of lift, vertical range, and offset C.G.). There were 12 different possible combinations. The subject began each task without prior knowledge of the amount of weight in the container.

The subject lifted the box, using the handles mounted on the container. He lifted the box from one prescribed height level to another at a set frequency of lift for a

14

TABLE 1
Vertical Range of Lifts Used for Testing the Effects
of Location of C.G. on Lifting (Experiment I)

Range	Starting Point	Ending Point
Floor to knuckle	Floor level	Measured knuckle height (MKH)
Floor to shoulder	Floor level	MKH + 20"
Knuckle to shoulder	MKH	MKH + 20"

*Experiment was conducted at the Texas Tech Labs

specified offset of the C.G. of the load. After the lift was completed, the lifting apparatus lowered the container to the initial level and the subject lifted the box again at the onset of the signal. During the period between lifts, the subject was free to adjust the weight of the load. The container's weight at the end of the 20 minute period was considered the subject's maximum acceptable weight of lift for that particular task combination.

Experimental Design:

A randomized complete block design with factorial treatment combinations was utilized. Each subject was considered as a block. A random number table was used to determine the order in which the experiment was to be performed by a given subject. Each subject under this randomized design performed the 12 possible treatment combinations. The layout of the experiment is given in Table 2.

Experimental Procedure:

The experimental procedure, with respect to the lifting task, was selected to be a modified psychophysical technique.

The lifting procedure associated with this experiment allowed the individual to subjectively adjust, based upon the individual's estimate of his working capacity, fatigue, and endurance, the amount that he could perform without straining or discomfort and without becoming tired, weakened, overheated, or out of breath. Lead weights were placed in or taken out of the box by the subject until the maximum weight the subject could lift repetitively was determined. The subject lifted at a specified frequency controlled by the cadence of a light, and a buzzer signaled the start of each lift.

Each subject was required to read and listen to a recording of instructions explaining the experiment and the task that was expected of the subject.

16

TABLE 2

Experimental Layout Used for Testing the Effects of Location of C.G. on Lifting. The Box Dimensions Were 12"X12"X7". (Experiment I)*

Height Level of Lift

		Floor to Knuckle		Floor to Shoulder		Knuckle to Shoulder	
		Offset		Offset		Offset	
		0"	4"	0"	4"	0"	4"
Subject 1	Frequency						
	Lifts/min	2					
		6					
Subject 2	Frequency						
	Lifts/min	2					
		6					
Subject 3							

*Experiment was conducted at the Texas Tech Labs

Each subject was required to perform the 12 possible treatment combinations. Each treatment combination was performed for approximately 20 minutes. A brief rest period was provided between each 20 minute period while the equipment was being adjusted for the subsequent task combination.

The subject was not provided with any external motivational cues, i.e., [such as encouragement to lift more] reference made to the fact that the individual was performing better or worse than an arbitrary reference value.

Experiment (II): Effect of Couplings

Experimental Variables:

1. Worker Variables

The subjects participating in this project were four naive male students with no experience in manual materials handling. The subjects selected were a stratified sample. The basis of stratification was strength and endurance. The first subject had high strength and high endurance. The second had high strength and low endurance. The third had low strength and high endurance. The fourth had low strength and low endurance. The subjects were allowed to use their "free style" lifting technique.

2. Task Variables

Frequency of Lift. The frequency of lift for each task consisted of one of four levels utilized in the experiment. These were: 0.1, 0.2, 1 and 6 lifts per minute. The subjects were paced in order to maintain the assigned lifting frequency for the duration of that particular lifting task combination.

Height and Vertical Range of Lift. The vertical range of lift consisted of three levels, each with a specific starting and terminating point. The combinations are given in Table 3.

Handles. The effect of having boxes with handles and without handles was studied.

18

TABLE 3
Vertical Range of Lifts Used for Testing the
Effects of Handles on Lifting (Experiment II)

Range	Starting Point	Ending Point
Floor to knuckle	Floor level	Measured knuckle height (MKH)
Floor to shoulder	Floor level	MKH + 20"
Knuckle to shoulder	MKH	MKH + 20"

Bakken (1979)

19

3. Environmental Variables

Once again, the environmental variables were not varied, but rather they were controlled and maintained constant throughout the experimental phase as in Experiment I.

The Task:

The subjects were required to perform lifting tasks. Each task was comprised of one level of each of the task variables (frequency of lift, vertical range, box size, and handles). There were 48 different possible combinations.

The lifting task required the use of a lifting apparatus, a container with or without handles, and lead weights. The subject lifted the container with both hands, in the sagittal plane, using a free style lifting technique. After the lift was completed, the lifting apparatus lowered the container to the initial level at the onset of the signal. The subject began the task without prior knowledge of the amount of weight in the container. The subject was free to adjust the weight of the container at any time during the task period (20 min.) until the maximum load the subject could lift repeatedly for a long period of time (a work shift) was reached. The subject was to continue repetition of the task until the 20 minutes were over, even if they arrived at their maximum weight before then. The container's weight at the end of the 20 minute period was considered the individual's maximum acceptable weight of lift for that particular task combination.

Experimental Design:

A randomized complete block design with factorial treatment combinations was utilized. Each subject was considered as a block. Each subject replicated the whole experiment three times. A random number table was used to determine the order in which the experiment was to be performed by a given subject. The layout of the experiment is given in Table 4.

TABLE 4
Experimental Layout Used for Testing the Effects of Handles
On Lifting (Experiment II)

				Height of Lift					
				Floor to Knuckle		Floor to Shoulder		Knuckle to Shoulder	
				Handles		Handles		Handles	
Subject 1	Repl. 1	Box	14"	Frequency Lifts/min	0.1 0.2 1 6	w'	w'o	w'	w'o
		Size	20	Frequency Lifts/min	0.1 0.2 1 6				
	Repl. 2	Box	14"	Frequency Lifts/min	0.1 0.2 1 6				
		Size	20	Frequency Lifts/min	0.1 0.2 1 6				
	Repl. 3		etc.						

Bakken (1979)

Experimental Procedure:

The experimental procedure, with respect to the lifting task, was selected to be a modified psychophysical technique.

The lifting procedure associated with this experiment allowed the individual to subjectively adjust, based upon the individual's estimate of his working capacity, fatigue, and endurance, the amount that he could perform without straining or discomfort and without becoming tired, weakened, overheated, or out of breath. Lead weights were placed in or taken out of the box by the subject until the maximum weight the subject could lift repetitively was determined. The subject lifted at a specified frequency controlled by the cadence of a light and buzzer signaling the start of each lift. Each subject was required to read and listen to a recording of instructions explaining the experiment and the task and what was expected of each subject.

RESULTS AND DISCUSSION

The data from the literature review were evaluated and organized into three categories: (1) lifting/lowering; (2) pushing/pulling; and (3) carrying. Pertinent results are given below. Sufficient data were found for additional subdivisions to be made in the lifting/lowering and pushing/pulling categories. For each of these subdivisions and for the undivided category of carrying, a summary was prepared of the best values presently available for use in preparing and/or revising standards on MMHA.

LIFTING AND LOWERING

Considerable research has been conducted on various aspects of lifting. Therefore the material in this category has been divided into five areas: Strength norms, capacity norms, physiological models, effects of frequency of lift on the amount of weight lifted, and effects of box size on the amount of weight lifted.

Strength Norms: Literature Review

Emanuel, et al. (1956) instructed 19 young students (17 to 28 years old) to lift "the greatest weight possible without a feeling of possible injury" using the psychophysical approach. The subjects then varied the weight of the object lifted by adding or subtracting 10 lb. bags of lead shots. They were required to lift with a straight, though not necessarily vertical, back. The subjects were classified as untrained in lifting and lifted an F-86H ammunition case 10-3/4 in. high, 25-1/2 in. wide, and 6-3/4 in. deep. The case had two handles at the top. Maximum acceptable weight for a single lift is given in Figure I.

The study discussed above gives estimates of the load magnitudes that a person can lift for different heights of lift. Two additional studies were concerned with muscular strength as related to lifting. Whitney (1958) studied the position of the foot and its effect on lifting force using
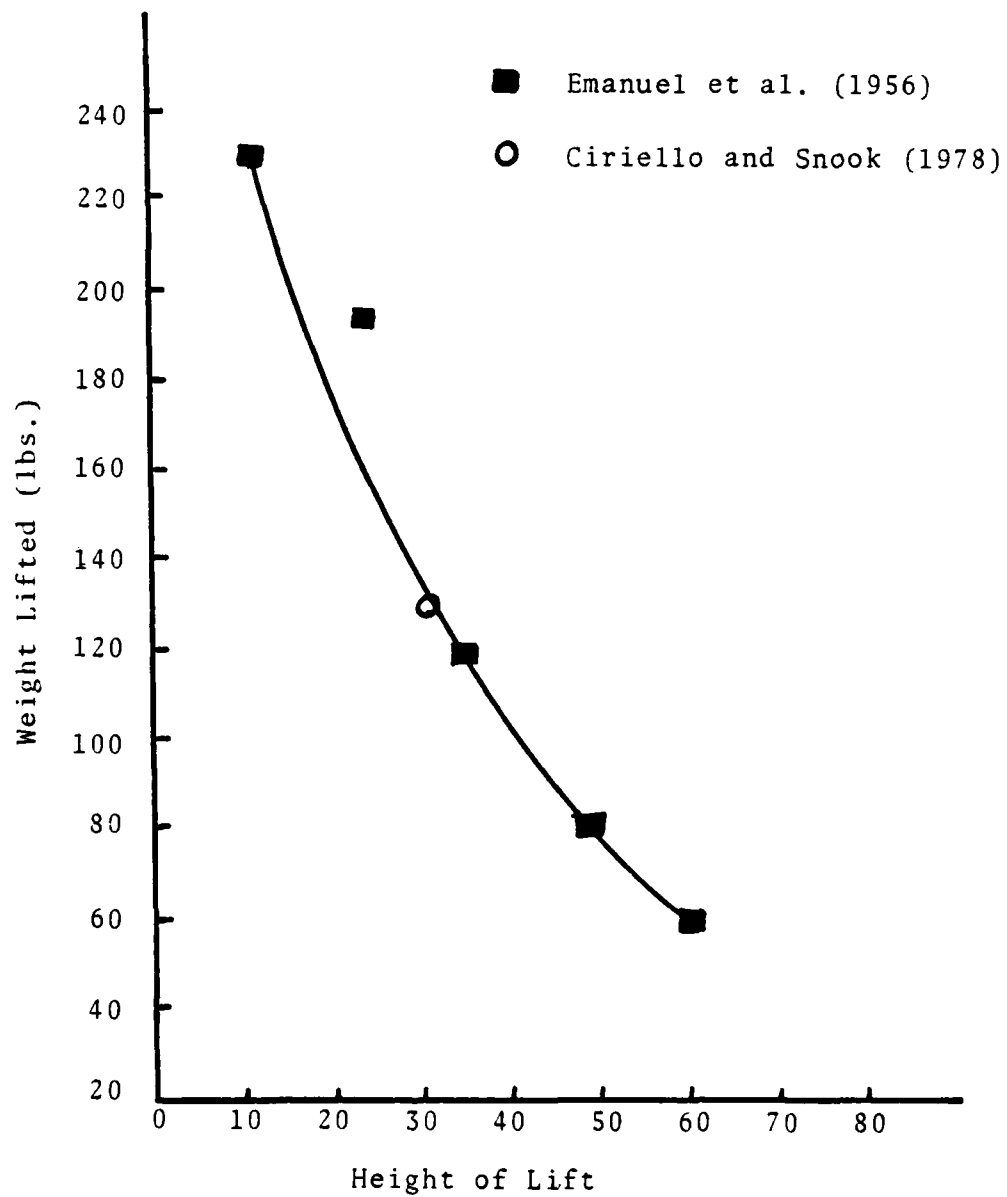
Figure 1: Maximum Acceptable Weight for Males and Different Heights (the lifting capacity of women is 6.5% of each plotted value)

eight male subjects. They were instructed to exert a steady maximum lifting force on a horizontal bar (1.3 inches dia.) placed in a frontal plane for a period of 3 sec. The distance between the hands was maintained at 15.7 inches. Three levels of grasp height were investigated: 4.9, 9.8, and 19.7 inches above ground level. Three distances of foot placement were considered: 11.8, 15.7 and 19.7 inches. The subjects adopted one of two types of lifting action, either a derrick action or knee action. The results indicated that the lifting force decreased as the distance between the feet or of the feet from the bar increased. This decrease, due to foot placement, was more significant as compared to the decrease in the lifting force due to the increase in grasp height. The maximum isometric force exertable on a horizontal bar varied from 33 to 264 lbs. for the different lifting conditions.

Chaffin, (1974) studied the lifting strength as demonstrated by employees in a standard position strength testing. A total of 103 jobs held by 411 men and women were evaluated for physical stress. The modal value for females (26 lbs.) was 65 percent of the modal value for men (40 lbs.). Women had a lifting strength mean of 30 lbs. with a standard deviation of 16 lbs, while the mean for men was 52 lbs. with a standard deviation of 23 lbs. Snook and Ciriello (1974) have also indicated that the weights and work loads acceptable to female workers were significantly different from those acceptable to male workers.

Strength Norms: Summary

The data in Figure 1 from Emanuel, et al. (1956) can be used as a summary for the strength norms for men. The data points are connected with a line to facilitate using the graph in predicting the weight lifted for other heights. It is worth mentioning that when the data of Ciriello and Snook (1978) for subjects performing one lift every 8 hours was plotted on the same graph (Figure 1), it was very close to

the line connecting Emanuel's data points. This in itself
adds to the reliability of Emanuel's data.

As Chaffin (1974) reported, women had a lifting strength
of about 65 percent of men. The graph in Figure I can be used
for estimating the weight lifted by a female to a certain
height by multiplying the value obtained from the graph by
0.65.

No data are available at the present for lowering
strength norms.

Capacity Norms: Literature Review

Snook and Irvine (1967) used a subjective criterion to
determine the maximum acceptable weight the male industrial
population could lift. Nine male subjects, between 25 and
37 years of age (average age 30.1 years) were used. They
were instructed to adjust the weight of a box until they
felt that it was the maximum amount that could be lifted
comfortably once every 15 minutes. Subjects were industrial
workers in good health. They performed a daily schedule of
push-ups, and pull-ups, and deep knee bend exercises in their
homes during the week prior to their scheduled participation
in the experiment.

During the first 4 days of the experiment, subjects were
instructed in the correct lifting procedures and given 18 prac-
tice trials at adjusting the weight of the lifted object by
lifting for varying periods of time. Subsequently, eighteen
5-minute sessions and three 30-minute sessions of repeated
lifting were performed by each subject. The object lifted
was similar to an industrial tote box, 13-1/2 in. x 19 in.
x 15 1/2 in. with two 7 in. x 1-5/8 in. handles. The box
weighed 10 lbs. and had a false bottom which could hold a
maximum of 40 lbs. of lead shot. Subjects made only one
judgement per lifting height in a single day. Each subject
made a total of 18 judgements: six for the floor to knuckle
height lift, six for the knuckle to shoulder height lift,
and six for the shoulder to reach height lift. For one

half of the judgements, the initial weight of the box was 30 lbs.; for the other half, 100 lbs. was the initial weight. The results of this study are shown in Table 5.

In a second study, Snook and Irvine (1968) used a psychophysical approach to determine the maximum acceptable frequency of lift for different combinations of height of lift and box weight. Three heights of lift were used: floor level to knuckle height, knuckle to shoulder height, and shoulder to reach height. Two weights were used, 35 and 50 lbs. Eight male workers from local industry performed as subjects. Their age ranged from 26 years to 37 years (average 31 years). They were trained in the same way as the subjects in the previous study (Snook and Irvine, 1967) were trained.

The subjects were asked to adjust the frequency of lift according to their sensations or feelings of fatigue. They were specifically instructed to imagine that they were on piece work, getting paid for the number of lifts each could make, but working a normal 8-hour shift that allowed each subject to go home without feeling fatigued. In other words, the subject should work as hard as he can without becoming tired, weakened, overheated, or out of breath. The experiment was replicated three times for each subject. The heart rate of the subjects was monitored and recorded.

The results indicated that there were no significant heart rate differences between the two loads, 35 lbs. and 50 lbs., while there were significant heart rate differences among the three heights of lift. Subjects maintained a mean heart rate of 112 beats per minute for floor to knuckle lift, while they maintained a mean heart rate of 99 beats per minute for the other two heights of lift. The final frequencies of lift selected by each worker were converted into ft-lbs/min. to provide a comparison between 35 lb. and 50 lb. weights of lift. A significant difference was found for these work loads among the three heights and two weights. The maximum

27

TABLE 5

Maximum Acceptable Weight (lbs.) of Lift for Males for
Three Different Heights of Lift*

Height of Lift	Mean	Std. Devia.	Percent of Population										
			95	85	75	65	55	50	45	35	25	15	5
Floor to Knuckle	66	11	48	51	59	62	65	66	67	70	73	81	84
Knuckle to Shoulder	62	9	48	50	56	59	61	62	63	65	68	74	76
Shoulder to Reach	60	10	44	47	53	56	59	60	61	64	67	73	76

Snook and Irvine (1967)

*Assuming a normal distribution. The box dimensions were 13.5"L x 19"W x 5.5"H. Frequency of lift was 1 lift every 15 minutes.

work loads acceptable to the industrial male workers are summarized in Table 6.

Snook, et al. (1970) conducted another study to determine the maximum weights and work loads acceptable to male industrial workers. The manual materials handling tasks involved lifting, lowering, pushing, pulling, and carrying tasks. Twenty-eight male subjects from the local industry participated in the experiment. They were all in good health. Three height ranges were used for lifting and lowering tasks: Floor level to knuckle height; knuckle height to shoulder height; and shoulder height to arm reach height. Force was the dependent variable for all tasks, except for paced carrying, where it was adjusted by varying the weight of the object being handled (tote box: 13-1/2 in. x 19 in. x 15-1/2 in. with two 7 in. x 1-5/8 in. handles). All tasks except carrying were performed at high, medium, and low rates of work. Subjects were instructed to adjust their work load to the maximum amount that they could perform without strain, discomfort, weakness or getting tired. Three subjects performed simultaneously. Each task took about 40 min. The results of the study for lifting and lowering are given in Tables 7 and 8. Results for the other tasks are presented in the subsequent categories of pushing/pulling and carrying.

Snook and Ciriello(1974) performed a similar study on female workers to find out the maximum weights and work loads acceptable to them. Thirty-one women served as subjects. Sixteen of these were housewives with a mean age of 35.6 years while the remaining 15 were workers from local industry with a mean age of 38.5 years. The experimental setup was identical to the one described in the previous study (Snook, et al., 1970). The results of this study are summarized in Tables 9 and 10.

Ciriello and Snook, (1978) investigated the effect of additional variables: object length (distance between the hands); object width (distance away from the body);

29

TABLE 6

Distribution of Maximum Workloads (ft.-lb./min.) Acceptable to Male
Industrial Workers for Three Different Heights
and Two Different Weights*

Height of Lift	Wt. of Object (lbs.)	Mean Work Load	Std. Devia.	Percent of Population										
				95	85	75	65	55	50	45	35	25	15	5
Shoulder to Reach	50	374	71	257	277	326	347	365	374	383	401	422	471	491
	35	342	71	225	245	284	315	333	342	351	369	390	439	459
Knuckle to Shoulder	50	454	102	286	314	385	414	441	454	467	494	523	584	622
	35	413	95	256	283	349	376	401	413	425	450	477	543	570
Floor to Knuckle	50	317	89	171	186	257	283	306	317	328	351	377	438	463
	35	244	49	164	178	211	225	238	244	250	263	277	310	324

Snook and Irvine (1968)

*Assuming a normal distribution. The box dimensions were 19"L x 13.5"W x 5.5"H.
Frequency of lift was selected by subject (Psychophysical method).

30

TABLE 7
Distribution of Maximum Weights (lbs.) of Lift and Lower
Acceptable to Male Industrial Workers*

Height Levels	Activity	Mean	Std. Devia.	Percent of Population										
				95	85	75	65	55	50	45	35	25	15	5
Floor to Knuckle	Lift	54	13	33	40	45	49	52	54	55	59	62	67	75
	Lower	62	20	29	41	48	54	59	62	64	70	75	83	95
Knuckle to Shoulder	Lift	63	14	29	38	43	47	51	53	54	58	63	68	76
	Lower	55	12	34	42	46	50	53	55	56	59	63	67	75
Shoulder to Reach	Lift	49	15	24	33	39	43	47	49	51	55	59	64	74
	Lower	44	12	24	32	36	40	43	44	46	49	52	57	64

Snook, et al. (1970)

*Assuming a normal distribution. A tote box measuring 13.5"L x 19"W x 5.5"H was used. The frequency of lift was randomly varied.

TABLE 8

Distribution of Maximum Workloads (ft.-lb./min.) for Lifting and
Lowering Tasks Acceptable to Male Industrial Workers for
Three Different Height Ranges*

Height Levels	Activity	Mean	Std. Devia.	Percent of Population										
				95	85	75	65	55	50	45	35	25	15	5
Floor to Knuckle	Lift	322	88	177	230	262	288	311	322	333	356	382	414	467
	Lower	539	178	246	354	419	470	517	539	561	608	659	724	832
Knuckle to Shoulder	Lift	468	105	294	359	397	427	455	468	481	509	539	577	642
	Lower	667	184	364	476	543	596	644	677	690	738	792	858	970
Shoulder to Reach	Lift	370	140	157	236	282	320	354	379	386	420	458	505	583
	Lower	471	169	193	296	357	406	450	471	492	536	585	646	749

Snook, et al. (1970)

*Assuming a normal distribution. The box dimensions were 13.5"L x 19"W x 5.5"H. The frequency of lift was randomly varied.

32

TABLE 9

Distribution of Maximum Weights (lbs.) Acceptable to Both Industrial
Women and Housewives during Lifting and Lowering
for Three Different Heights*

Height of Lift	Activity		Mean	Std. Devia.	Percent of Population										
					97	85	75	65	55	50	45	35	25	15	5
Shoulder to Reach	Lift	Ind. women	29	4	23	25	36	27	29	29	29	3	32	34	35
		Housewives	18	4	12	14	15	16	18	18	18	20	21	22	24
	Lower	Ind. women	30	5	22	25	27	28	29	30	31	32	33	35	38
		Housewives	19	5	10	13	16	17	18	19	20	21	22	25	28
Knuckle to Shoulder	Lift	Ind. women	34	7	22	27	29	31	33	34	35	37	38	41	46
		Housewives	21	4	15	17	18	19	21	21	21	23	23	25	27
	Lower	Ind. women	35	7	23	28	31	32	34	35	36	38	39	42	46
		Housewives	22	7	10	15	18	19	21	22	23	25	26	29	34
Floor to Knuckle	Lift	Ind. women	37	7	25	30	33	34	36	37	38	40	42	44	48
		Housewives	21	5	12	15	17	19	20	21	23	23	24	27	30
	Lower	Ind. women	38	6	28	32	34	36	37	38	39	40	43	44	48
		Housewives	22	7	10	15	18	19	21	22	23	25	27	29	34

Snook and Ciriello (1974)

*Assuming a normal distribution. The box dimensions were 13.5"L x 19"W x 5.5"H.
Frequency of lift was selected by subject (psychophysical method).

TABLE 10
Distribution of Maximum Workloads (ft. lb./min.) Acceptable to Both Industrial Women and Housewives While Lifting and Lowering for Three Different Heights*

Height of Lift	Activity		Mean	Std. Devia.	Percent of Population										
					97	85	75	65	55	50	45	35	25	15	5
Shoulder to Reach	Lift	Ind. women	252	34	197	217	230	239	248	252	256	265	274	287	307
		Housewives	145	33	91	111	124	132	141	145	149	158	160	179	199
	Lower	Ind. women	411	80	280	328	358	380	401	411	421	442	404	494	543
		Housewives	236	52	151	183	202	216	229	236	242	256	271	289	321
Knuckle to Shoulder	Lift	Ind. women	335	48	255	285	303	316	329	355	341	354	367	385	415
		Housewives	203	41	135	160	176	187	198	203	208	219	230	246	271
	Lower	Ind. women	501	111	379	446	488	518	547	561	575	604	635	676	745
		Housewives	303	55	213	246	267	282	296	303	310	324	339	359	393
Floor to Knuckle	Lift	Ind. women	241	52	156	188	207	221	234	241	247	261	276	294	320
		Housewives	121	31	70	89	101	109	117	121	125	133	142	153	172
	Lower	Ind. women	398	74	276	321	349	369	389	398	407	426	446	475	520
		Housewives	216	55	126	159	180	195	209	210	223	237	251	273	300

Snook and Ciriello (1974)

*Assuming a normal distribution

34

lifting distance; and pushing and pulling height. Fifteen male industrial subjects were used. Sixty one different lifting, lowering, pushing, and carrying tasks were performed in a moderate environment of 21.5°C dry bulb and 45 percent relative humidity. There were no significant weight differences in object length. There were no significant weight differences ($p < 0.01$) among three object widths (14.2, 19.3 and 29.5 in.), but only for those lifts between floor level and knuckle height. Significant weight differences ($p < 0.01$) also occurred among three lifting distances (9.8, 20.0, and 29.9 in).

Snook (1978) attempted to integrate the results of all the studies that he had conducted over a period of 10 years into a format that considered all of the significant variables. Tables 11 and 12 summarized that attempt. However, it is important to note that not all of the values in these tables were based upon the experimental data; assumptions had to be made to fill in the gaps that have not yet been studied. For example, lifting data for the 19.3 inch and 29.5 inch object widths had not been collected at the time of preparing the table. Therefore, the values in Table 12 for 19.3 and 29.5 inches represent adjustments of the 14.0 inch female data based upon the proportional differences observed in male workers. Similar adjustments were also made for the other frequencies and distances that had not yet been studied.

Ayoub, et al. (1978) conducted a study to determine and model the lifting capacity of 73 male and female industrial workers. Six different height levels and four frequencies were employed. The height levels were: (1) floor to knuckle; (2) floor to shoulder; (3) floor to reach; (4) knuckle to shoulder; (5) knuckle to reach; and (6) shoulder to reach. The frequencies studied were 2,4,6, and 8 lifts/min. The experimental procedure was similar to the one described in the study by Snook, et al. (1970). Subjects were asked to

TABLE 11

Maximum Acceptable Weight (lbs.) of Lower (or Lower) for Males and Females for Different Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift		MALES — One Lift Every				FEMALES — One Lift Every			
				9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
Floor to Knuckle	29.5"	30"	x	40	57	77	90	26	33	44	53
			o	10	14	21	26	5	5	7	9
		20"	x	40	59	79	95	29	33	46	55
			o	12	15	22	26	5	7	7	9
		10"	x	40	66	90	106	33	37	53	62
			o	10	19	24	29	5	7	9	10
	19.3"	30"	x	46	66	90	66	31	37	53	62
			o	14	19	26	31	5	7	7	10
		20"	x	46	68	92	110	31	40	53	64
			o	15	21	28	33	7	7	10	10
		10"	x	55	77	106	123	37	44	62	73
			o	17	22	31	38	7	9	9	12
	14.2"	30"	x	50	73	99	117	35	42	57	68
			o	15	21	29	34	7	7	9	10
		20"	x	53	75	103	121	35	44	59	70
			o	15	22	29	36	7	7	10	12
		10"	x	62	86	117	136	42	48	66	79
			o	19	24	34	41	9	9	12	13

Snook (1978)

36

Maximum Acceptable Weight (lbs.) of Lower for Males and Females for Different Height Levels, Widths of object, and Vertical Distances

TABLE 11 (continued)

Height of Lift	Width of object (in. Away from Body)	Vertical Distance (in.) of Lift	MALES One Lift Every				FEMALES One Lift Every			
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
	29.5"	30" x	40	48	55	66	29	31	37	42
		30" o	12	14	15	21	5	5	7	9
		20" x	42	53	64	75	31	33	40	46
		20" o	14	17	17	22	7	5	9	9
		10" x	51	64	75	88	37	37	48	55
		10" o	15	19	19	28	9	9	9	10
Knuckle to Shoulder	19.3"	30" x	40	48	59	66	29	31	37	42
		30" o	12	14	17	21	5	5	7	9
		20" x	42	53	66	75	31	33	40	46
		20" o	14	17	21	22	7	5	9	9
		10" x	51	64	79	88	37	37	48	53
		10" o	15	19	22	28	9	9	9	10
	14.2"	30" x	44	51	64	73	29	33	40	46
		30" o	12	15	19	21	7	7	9	9
		20" x	46	57	72	81	33	35	44	48
		20" o	14	17	21	24	7	7	9	10
		10" x	55	68	86	97	40	42	51	57
		10" o	15	21	24	28	19	7	10	12

Snook (1978)

37

Maximum Acceptable Weight (lbs.) of Lower for Males and Females for Different
Height Levels, Widths of Object, and Vertical Distances

TABLE 11 (continued)

Height of Lift	Width of object (in. Away from Body)	Vertical Distance (in.) of Lift	MALES — One Lift Every				FEMALES — One Lift Every			
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
	29.5"	30" x	31	40	48	55	24	26	33	37
		30" o	10	10	14	15	5	3	5	5
		20" x	35	44	55	62	26	29	35	40
		20" o	10	12	15	17	5	3	5	7
		10" x	40	51	64	73	33	33	40	40
		10" o	12	15	19	21	5	5	7	7
Shoulder to Reach	19.5"	30" x	31	40	48	55	24	26	33	37
		30" o	10	10	14	15	5	3	5	5
		20" x	37	44	55	62	26	29	35	40
		20" o	10	12	15	17	5	3	5	7
		10" x	40	51	64	73	33	33	40	40
		10" o	12	15	19	21	5	5	7	7
	14.2"	30" x	33	42	53	59	26	29	35	40
		30" o	12	12	15	17	3	5	5	7
		20" x	35	46	69	66	29	31	37	42
		20" o	12	14	19	19	5	5	7	7
		10" x	42	55	68	77	33	35	44	62
		10" o	14	17	21	24	7	7	7	9

Snook (1978)

38

TABLE 12

Maximum Acceptable Weight (lbs.) of Lift for Males and Females for Different Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift		MALES — One Lift Every				FEMALES — One Lift Every			
				9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
Floor to Knuckle	29.5"	30"	x	37	48	66	79	26	31	44	51
			o	12	14	15	21	5	7	9	10
		20"	x	40	51	68	82	26	33	44	53
			o	10	14	19	22	5	7	9	10
		10"	x	46	57	77	93	31	37	51	59
			o	14	15	22	26	7	7	10	12
	19.5"	30"	x	42	57	77	93	29	37	51	59
			o	12	17	24	28	7	7	10	12
		20"	x	44	60	82	95	29	37	53	62
			o	12	17	24	29	7	9	10	12
		10"	x	51	66	90	108	35	44	59	70
			o	15	21	28	31	7	9	12	14
	14.2"	30"	x	48	64	86	101	33	42	55	66
			o	15	19	26	31	7	7	12	12
		20"	x	51	66	88	106	35	42	57	68
			o	15	19	23	31	7	9	12	14
		10"	x	60	75	101	119	40	48	66	77
			o	17	21	29	36	9	9	12	15

Snook (1978)

TABLE 12 (continued)

Maximum Acceptable Weight (lbs.) of Lift for Males and Females for Different Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift		MALES					FEMALES		
				One Lift Every					One Lift Every		
				9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
	29.5"	50"	$\bar{x}$	33	44	55	62	20	24	29	33
			σ	10	12	15	17	3	3	5	5
		20"	$\bar{x}$	37	48	62	68	24	26	33	37
			σ	10	15	17	21	2	5	5	5
		10"	$\bar{x}$	44	57	73	82	29	31	40	44
			σ	12	17	21	22	3	5	5	7
	19.5"	50"	$\bar{x}$	33	44	55	62	20	24	29	33
			σ	10	12	15	17	3	3	5	5
		20"	$\bar{x}$	37	48	62	68	24	26	33	37
			σ	10	15	17	21	2	5	5	5
		10"	$\bar{x}$	44	57	73	82	29	31	40	44
			σ	12	17	21	22	3	5	5	7
Shoulder to Reach	14.2"	30"	$\bar{x}$	35	46	60	66	22	26	33	35
			σ	10	15	17	19	3	3	3	5
		20"	$\bar{x}$	40	53	66	75	24	29	35	40
			σ	12	15	19	22	5	5	5	7
		10"	$\bar{x}$	48	62	77	88	31	35	42	48
			σ	14	19	24	26	3	3	7	7

Snook (1978)

40

Maximum Acceptable Weight (lbs.) of Lift for Males and Females for Different
Height Levels, Widths of Object, and Vertical Distances

TABLE 12 (continued)

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift		MALES One Lift Every				FEMALES One Lift Every			
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
	29.5"	30" x	42	46	60	66	26	29	35	40
		30" o	10	14	15	19	3	5	7	7
		20" x	44	53	66	75	29	31	40	44
		20" o	12	15	19	21	3	7	7	9
		10" x	53	62	77	88	33	37	46	51
		10" o	14	19	22	24	5	7	9	10
Knuckle to Shoulder	19.3"	30" x	42	46	60	66	26	29	35	40
		30" o	10	14	15	19	3	5	7	7
		20" x	44	53	66	75	29	31	40	43
		20" o	12	15	19	21	3	7	7	9
		10" x	44	51	64	71	31	31	37	41
		10" o	10	15	19	22	5	5	7	9
	14.2"	30" x	46	57	71	79	33	33	42	46
		30" o	12	17	21	24	3	7	7	10
		20" x	55	68	84	95	35	40	48	55
		10" o	14	19	24	28	5	9	10	12

Snook (1978)

41

lift a tote box, which had a dimension in the sagittal plane of 12 in., 18 in., or 24 in. Strength and anthropometric measurements were recorded for each subject and were used to develop lifting capacity prediction models. Lifting capacity values for the various height levels are summarized in Table 13.

Capacity Norms: Experimental Findings

Experiment (I): Unbalanced Loads

The maximum acceptable weights for experiment (I) are listed in Table 14 for different frequencies of lift, different height levels and different locations of center of gravity of the load lifted.

An analysis of variance of the data showed that the frequency of lift had a significant effect on the amount of weight lifted ($p < 0.01$). Subjects lifted less weight for the frequency of 6 lifts/min.

The three height levels had a significant main effect on the maximum acceptable weights ($p < 0.01$). However, only the floor to knuckle height was significantly different from the other levels. Subjects lifted more weight from floor to knuckle height.

The location of the center of gravity (C.G.) of the load lifted had a significant effect on the amount of weight lifted ($p < 0.01$). Subjects lifted less weight when the C.G. of the load lifted was shifted a distance of 4 in. in the frontal plane from the center of gravity of the box used.

Experiment (II): Effect of Couplings

The effects of handles on the maximum acceptable weight of lift are presented in Figure 2.

An analysis of variance of the data showed that the frequency of lift had a significant effect on the amount of weight lifted ($p < 0.01$). Subjects lifted less weight for the frequency of 6 lifts/min.

TABLE 13
Distribution of Maximum Weights (lbs.) of Lift Acceptable to Male and Female Industrial Workers (Corrected for one lift/min.) for Various Height Levels

Height of Lift	Sex	Mean	Std. Devia.	Percent of Population										
				95	85	75	65	55	50	45	35	25	15	5
Floor to Knuckle	Male	61	17	33	44	50	55	59	61	63	68	73	79	89
	Female	37	7	26	30	33	35	36	37	38	40	42	44	48
Floor to Shoulder	Male	51	12	31	39	43	47	50	51	53	56	60	64	71
	Female	31	7	20	24	27	29	30	31	32	34	36	38	42
Floor to Reach	Male	49	11	31	38	41	45	48	49	51	53	57	61	68
	Female	28	5	19	22	24	26	27	28	29	30	32	34	37
Knuckle to Shoulder	Male	57	15	33	42	47	52	56	57	59	63	68	73	82
	Female	32	7	21	35	27	29	31	32	33	35	36	39	43
Knuckle to Reach	Male	54	11	36	42	46	49	52	54	55	58	61	65	71
	Female	26	5	18	21	23	24	26	26	27	28	30	31	34
Shoulder to Reach	Male	44	10	26	33	36	40	42	44	45	48	51	54	61
	Female	26	4	19	21	23	24	25	26	26	27	29	30	33

Ayoub, et al. (1978)

*Assuming a normal distribution. The box dimensions were (width x height x length): 12"x7"x12", 12"x7"x18", and 12"x7"x24".

43

TABLE 14

Maximum Acceptable Weights for Males Performing Lifting
Tasks at Different Frequencies of Lift, Different
Height Levels, and Different Locations of
C.G. of Load Lifted (Experiment I)*

Frequency of Lift (lifts/min.)	Height Level	Location of C.G. of Load Lifted	Ave. Weight Lifted (lbs.)
2	F^1 - K^2	0"[4]	63
2	F - S^3	0"	58
2	K - S	0"	56
2	F - K	4"[5]	63
2	F - S	4"	54
2	K - S	4"	50
6	F - K	0"[4]	59
6	F - S	0"	43
6	K - S	0"	45
6	F - K	4"	60
6	F - S	4"	38
6	K - S	4"	42

1. F = Floor height

2. K = Knuckle height

3. S = Shoulder height

4. 0" = C.G. of load lifted is at the exact same point as the C.G. of the box used

5. 4" = C.G. of load lifted is shifted 4" in the frontal plane from the C.G. of box used. A drawing which illustrates a shifted load from the center of gravity is presented for the reader.

Plan View of
Box

(12"LX12"WX7"H)

4"

B   A
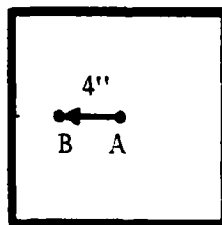
A - Center of Gravity
B - Shifted Load

*Data generated at Texas Tech Labs.
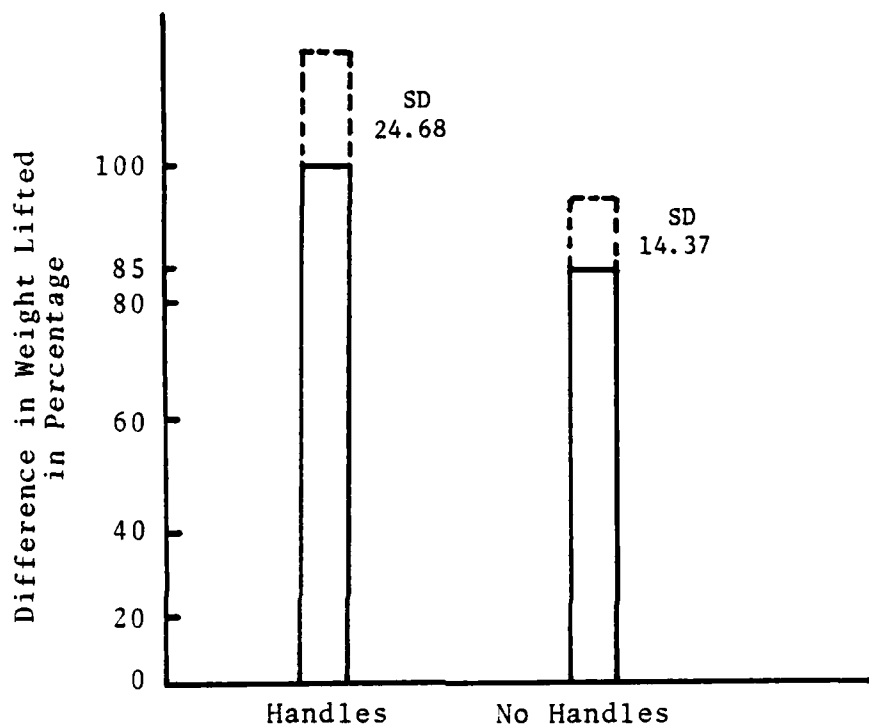
Figure 2:   Effects of the Presence of Handles
on Lifting Capacity (Bakken, 1979).

Significant weight differences (p<0.01) were found among the three height levels. Subjects lifted more weight from floor to knuckle height.

The two lengths of the box studied (14 in. and 20 in.) did not have any significant effect on the amount of weight lifted.

Equipping boxes with handles had a pronounced effect on the amount of load lifted by the students (p<0.01). Subjects were able to lift 16 percent more weight when boxes were equipped with handles, as shown in Figure 2.

Capacity Norms: Summary

At the present time there is no general agreement regarding the capacity limits for lifting and lowering tasks for male and female workers. Table 15 gives a summary of the lifting capacity of male and female workers; the values of this table were formulated by adjusting the lifting capacity values for the box size and frequency effects generated by Ayoub, et al. (1978) and Snook (1978). A linear box size and frequency of lift effect were assumed for this purpose. The box size used here was the box dimension in the sagittal plane. According to Snook (1978), the lifting capacity is not affected by the box dimension in the frontal plane as it has been shown to affect capacity in the sagittal plane. The standard deviation value given in table 15 is the larger of the values generated by Ayoub, et al. (1978) and Snook (1978).

For the floor to shoulder height, floor to reach height, and knuckle to reach height levels, the lifting capacity values recommended by Ayoub, et al. (1978) have been used, as there were no other lifting capacity data available in the literature for these height levels. For the same reason, Snook's (1978) data for the frequencies of 1 and 12 lifts/ min. were used, while for the frequencies of 2 and 8 lifts/ min., Ayoub, et al. (1978) data were used. For the frequency

TABLE 15

Mean and Standard Deviation of the Maximum Recommended Weight of Lift (lbs.) for Male and Female Workers

Height of Lift	Box Dimension in the Sagittal Plane		MALE WORKERS						FEMALE WORKERS					
			Frequency of Lift/min											
			1	2	4	6	8	12	1	2	4	6	8	12
Floor to Knuckle	12	x̄	67	61	53	49	46	39	44	41	35	34	29	25
		σ	19	21	15	18	17	12	7	3	7	8	7	7
	18	x̄	59	57	52	48	43	34	39	30	28	27	26	23
		σ	17	19	21	15	14	9	7	7	11	7	5	5
	24	x̄	53	51	47	53	39	31	34	28	27	27	25	21
		σ	17	15	17	11	18	9	7	5	6	5	6	5
Floor to Shoulder	12	x̄	52*	51	48	45	42	36*	29*	29	29	28	28	27*
		σ	13	14	12	13	14	14	7	7	3	8	4	2
	18	x̄	54*	53	51	49	47	43*	32	32	30	28	26	22*
		σ	7	7	13	11	15	10	6	6	7	10	5	4
	24	x̄	51*	51	59	47	45	41*	30	29	28	26	25	22*
		σ	11	11	10	8	14	12	6	6	4	5	8	7
Floor to Reach	12	x̄	48*	47	45	42	40	35*	28*	27	26	25	24	21*
		σ	11	11	13	7	8	6	5	5	6	6	4	6
	18	x̄	57*	54	47	40	33	19*	29	28	27	25	23	22*
		σ	14	14	13	9	8	4	5	5	5	4	4	1
	24	x̄	41*	41	39	38	37	34*	27	26	25	24	23	20*
		σ	12	12	3	9	10	8	6	6	7	5	4	5

47

TABLE 15 (continued)

Mean and Standard Deviation of the Maximum Recommended Weight of Lift (lbs.) for Male and Female Workers

Height of Lift	Box Dimension in the Sagittal Plane		MALE WORKERS						FEMALE WORKERS					
			Frequency of Lift/min											
			1	2	4	6	8	12	1	2	4	6	8	12
Knuckle to Shoulder	12	x̄	53	51	48	44	41	34	32	31	30	28	26	25
		σ	15	12	16	14	12	9	5	8	5	5	8	3
	18	x̄	59	57	53	49	44	31	29	29	29	28	25	20
		σ	14	16	19	14	12	9	5	8	5	5	7	3
	24	x̄	46	45	42	39	36	31	29	28	26	25	23	19
		σ	14	16	15	19	16	3	5	6	7	6	5	4
Knuckle to Reach	12	x̄	49*	47	43	40	36	29*	28*	28	27	25	24	22*
		σ	15	15	9	11	8	3	8	8	6	5	7	6
	18	x̄	55*	53	48	41	40	31*	26	26	25	25	24	23*
		σ	9	9	8	7	11	10	4	4	3	4	4	4
	24	x̄	54*	52	48	44	40	32*	32	31	29	26	23	19*
		σ	13	13	7	5	7	4	5	5	6	2	5	5
Shoulder to Reach	12	x̄	50	49	46	40	33	24	27	26	24	21	19	14
		σ	15	5	14	12	9	9	3	5	4	4	5	2
	18	x̄	45	41	40	38	33	24	25	24	22	20	17	13
		σ	12	10	12	17	9	5	3	4	3	4	5	3
	24	x̄	49	40	39	38	34	24	26	25	25	22	20	13
		σ	12	11	11	11	9	5	3	5	4	3	3	2

Ayoub, et al. (1978), Snook (1978)

*Data extrapolated from data generated for the other lifting frequencies

48

of 4 and 6 lifts/min., Snook's (1978) data were adjusted for box size and frequency. Then the average of these two values (Snook, 1978; Ayoub, et al. 1978) was computed. Larger standard deviation values were used for this purpose, These values were then adjusted to show a linear frequency effect.

Physiological Models: Literature Review

After a thorough review of the literature, it was found that very few researchers have attempted to develop prediction models for the energy cost of lifting or lowering tasks. These efforts were mainly made by Chaffin (1967), Åberg, et al. (1968), Garg, (1976) and Frederik (1959).   Some researchers have used the oxygen uptake of a subject while performing a lifting task as a measure of the load by dividing the O_2 uptake for the task by the subject's maximum O_2 uptake to determine the maximum load that can be lifted (Åberg, 1961); to determine the maximum frequency of lifting (Jorgensen, et al., 1974); and to assess the physical load on a subject while performing a moderate or strenuous task using time standards set by traditional industrial engineering methods.   A few other researchers (Datta, et al., 1973; Goldman, et al., 1962) have developed prediction models for energy cost, but these were for tasks other than lifting or lowering.

Frederik's Model

In his study, Frederik (1959) conducted tests to determine the energy cost for lifting various weights in four different height ranges.   Each lift was performed over a 20 in. vertical distance, in a range of 0 to 20, 20 to 40, 40 to 60, and 60 to 80 in.   The weights lifted ranged from 20 to 65 pounds.   A graph was plotted from the experimental results with an ordinate of the energy consumption in gram-calories per foot-pound and an abscissa of the weight lifted in pounds.   It should be noted that the energy consumed was

determined for lifting in a single performance. The following relationship was suggested to give the rate of energy expended for manual lifting:

$$E = (f * a * w * c)/1000$$

where:

E = total energy expenditure/hour in kilocalories (no more than 200 Kcal/hr for an average man),

f = number of lifts/hour,

a = lifting height in feet,

w = weight of the load in pounds, and

c = consumption of energy in gram-calories per foot-pound taken from the graph at a certain lifting range.

The limitations of this model are that:

1. the consumption of energy in gram-calories per foot-pounds was based on a single performance of lifting.
2. the effect of the posture during lifting is not taken into account,
3. the effect of body weight is not taken into consideration,
4. it is valid only for lifting in the sagittal plane,
5. the effect of box size is not accounted for in this model, and
6. it is valid for lifting but not for lowering tasks.

Chaffin's Model

Chaffin (1967) developed a model for the prediction of metabolic energy expenditure during arm activities. Chaffin's model is as follows:

$$E_{ijk} = f(s_{ik} * a_{ij} * T_i^{bi})$$

where:

E_{ijk} = predicted metabolic rate (Kcal/min) for ith muscle action, jth articulation angle and kth subject,

s_{ik} = individual difference parameter for ith muscle action and kth subject,

a_{ij} = muscle group efficiency coefficient for ith muscle action and jth articulation angle,

T_i = resultant torque at articulation spanned by muscles that produce the ith muscle action (kg=to-cm). and

bi = a parameter, which transforms the rate of increase in torque of ith muscle action to the increase in energy expenditure rate.

The limitations of this model are that:

1. The model is primarily limited to static weight holding arm activities in the sagittal plane,

2. the precise knowledge of body position (arm angles), resultant torques, and individual size differences is required,

3. the computations are laborious and time consuming,

4. it cannot be applied with reliable accuracy in the case of dynamic lifting or lowering, and

5. it does not take into account the effects of posture and box size.

°
Aberg's Model

°
Aberg, et al. (1968) developed a model based on the principle that mechanical work is related to a change of the positional energy of a mass, a change of the velocity of a mass, and frictional losses. The resulting model was:

V_{O_2} = oxygen consumption rate due to (Basal metabolism + posture + body motion + motion of tool and work piece),

or

$$V_{O_{2comp}} = BW_n * k_1 + BW_{cl} * k_2 + BW_{cl}(GCB_h * k_3 + GCB_v * k_7)$$

basal   posture   body motion
metab.

$$+ (WWP + WT)(L_{ha} * k_5 + u * L_{hc} * k_6 + L_{vu} * k_7 + L_{vd} * k_8)$$

motion of tool and work piece

where:

$V_{0_{2comp}}$ = computed oxygen uptake

BW_n = body weight, naked

BW_{cl} = body weight, with clothing

GCB_h = horizontal displacement per time unit of the body's center of gravity

GCB_v = vertical displacement per time unit of the body's center of gravity, up plus down

WWP = weight of work piece

WT = weight of tool

L_{ha} = horizontal displacement per time unit of tool and work piece, arm work

L_{hc} = horizontal displacement per time unit of tool and work piece, carrying or dragging

L_{vu} = upward vertical displacement per time unit of tool and work piece, lifting

L_{vd} = downward vertical displacement per time unit of tool and work piece, lifting

u = coefficient of friction in horizontal movement

k_1-k_8 = constants.

Limitations of the model are that:

1. Although the model is simple, it is difficult to determine the body's center of gravity,
2. it does not take into account the effect of posture on the energy expenditure while lifting,
3. the effect of sex is neglected,
4. it is valid only for lifting in the sagittal plane,
5. the effect of box size is not accounted for in this model.

Garg's Model

Garg (1976) developed regression equations to estimate metabolic energy expenditure rate for MMHA with reasonable

accuracy (coefficient of variation - 10%).

$$\Delta E = 10^{-2} f [0.13BW + 0.40L + 0.51 * 10^{-4} L^3 + 0.77 \, SXL$$

$$-0.31 \times 10^{-2} SxBWxL + T_{SQ}(0.067BW + 0.26L) + T_{ONE}$$

$$(0.56L) + T_{ARM} (-0.10BW + 0.49L - 0.26*10^{-2} S*BW*L].$$

where:

ΔE = net metabolic rate of lifting (Kcal/min.),

f = frequency of lifting (lifts/min.),

BW = body weight (lbs.),

L = load (lbs.),

S = sex (male-1, female-0),

T_{SQ} = squat lift (1 for squat lift, otherwise 0),

T_{ARM} = arm lift (1 for arm lift, otherwise 0), and

T_{ONE} = one hand lift (1 for one hand lift, otherwise 0).

The resulting regression equation for lowering was:

$$\Delta E = 10^{-2} f [0.10BW + 0.74L + 0.26S*BW - 0.30 \times 10^{-2} BW*L$$

$$+ T_{SQ} (0.09BW - 0.016S*BW) + T_{ARM} (-0.07BW - 0.4L$$

$$-0.02S \cdot BW = 0.29 \times 10^{-2} BW*L + 0.5 \times 10^{-4} S*L^3)].$$

The notations are the same as those for lifting. The limi-
tations of these models are that:

1. they are only valid for lifting and lowering in the
    sagittal plane,

2. only two height ranges (0-32in. and 32-60 in.) were
    studied (It was suggested by the author that in
    order to determine the energy expenditure for a
    height range that falls between the two ranges, the
    job can be divided into two tasks. The first task
    would be within the first height range and the
    second task would be within the second height range.
    The total metabolic rate for the two tasks could
    then be calculated using the model. This assump-
    tion of additivity needs to be verified.).

3. they do not take into account the effect of box size,

for the model was developed using only one box size, and

4. some operator-related variables were not taken into account, such as surface area of the body and lean body mass (free body weight).

Physiological Models: Summary

From the above literature review, it can be seen that very few prediction models have been developed to predict the energy cost of lifting and lowering tasks, and that all of these models have their limitations. Therefore, there is a need for developing a more complex prediction model which takes into account the effect of additional task-related variables such as the body's angle of twist and box size. The need for studying the effect of the body's angle was pointed out by Herrin, et al. (1974) when they recommended that research should strive to provide information about postures other than the sagittal plane. Troup (1965) also emphasized this point when he reported that in 100 cases of back pain in industry, 39 were caused by lifting and 33 by a twisting movement of the spine, 25 of which occured when lifting.

There is also a need for the inclusion of some extra operator-related variables in order to account for the variability between individuals. Lean body mass and sur-face area of the body are two examples of these variables.

For a single lifting performance in the sagittal plane, Frederik's model (1959) is the only available model that gives the rate of energy expenditure in gram-calories per foot pound. The limitations of this model are that it does not take into account the effects of posture during lifting, the body weight of the subject, or the box size.

The most comprehensive models available at present for estimating the metabolic energy expenditure for lifting and lowering tasks are Garg's (1976) models as given in this sec-tion. In table 16, Garg (1976) gives the weight lifted in

TABLE 16
Weight Lifted (lbs.) by a 169 lb. Male at
Different Frequencies Resulting in an
Energy Consumption of 5 Kcal/min.*

Lifting Technique	Frequency of Lift (lifts/min.)	Wt. Lifted (lbs.)
Squat lifting (floor - 31.49")	4	48
	6	18
	8	7
Stoop lifting (floor - 31.49")	4	73
	6	35
	8	24
Arm lift (31.49" - 59")	4	114
	6	79
	8	59

Garg (1976)

*Box Dimensions were 12"W, 7"H, 6.5"D

kilograms by a 169 lb. male at a certain frequency that will tax him at 5 Kcal/min. for a certain lifting technique.

Effect of Frequency: Literature Review

It is obvious that the frequency of lift plays a very important role in determining the amount of weight that can be lifted by an individual. The higher the frequency of lift, the more energy he will expend and the sooner he will be fatigued.

Van Wely (1961) suggested that physiological efficiency depends not only on the weight lifted but also on the number of lifts per unit time.

Åberg (1961) investigated baling operations in a pulp factory. The experiment revealed a marked dependence on the relationship between the momentary work load and the distribution of pauses.

Bastina, et al. (1961) examined 146 women workers at two brick works. These women were permanently engaged in transporting small loads during the entire work day. It was found that these women suffered from reproduction disturbances, physiological time shifts and occupational diseases of the skeletal and motor systems. The authors provided no standards for the total weight shifted per day by women. However, they did recommend a load of 44 lbs. as the maximum weight for a single lift.

Noro (1967) emphasized that in trying to fix the maximum permissible weight to be carried by one worker, many factors must be taken into consideration, such as duration of carrying, technique, work breaks, etc.

Jorgensen, et al. (1974) conducted an experiment on repetitive lifting of loads from floor to table. Four males and four females participated in the experiment as subjects. For each subject, they determined both the maximum load which could be lifted from floor to table height and the maximum oxygen uptake. From the maximum load, they calculated the relative load of 10, 25, 50, and

75 percent. Lifting with at least three different frequencies was performed with each relative load. The maximum lifting frequency which did not demand more than 50 percent of the subject's VO_2 max was then determined for each relative load for each of the subjects. Their results showed that the maximum lifting frequency of females was about 70% of that for the males at the same relative burden.

Aquilano (1968) studied the effect of pace on energy expenditure and showed that increasing the pace of handling cartons was accompanied by an increase in the energy expenditure.

Hamilton and Chase (1969), in an experiment to determine the main differences in the effects of variations of load weight and work pace on carton handling tasks, found that pace and weight had no significant effects on energy expenditure and heart rates. They also found from the trend analysis of work pace on the energy expenditure rate that the relationship between work pace and energy expenditure was linear. In their conclusions, they recommended moving heavier weights at a slower pace and lighter weights at a faster pace.

Ronnholm et al. (1962), in a study of one handed lifting (lifting a weight of 11 lbs. from a height of 24.8 in. to a height of 29.5 in. and then lowering it) varied the rate of lift from 10 to 40 lifts/min. They found that the optimum efficiency in terms of energy expended was reached at approximately 30 lifts/min. Aghzadeh (1974) fitted a least square regression line to the data for the floor to knuckle height lift obtained by Snook (1971) using three different frequencies (1, 3.75, and 4.29 lifts/min.). The line had a negative slope, i.e., the load lifted decreased with the increase in the frequency.

Snook and Irvine, (1968) utilized a psychophysical approach to determine the maximum frequencies of lift acceptable to male industrial workers. The subjects were asked to perform a repetitive lifting task using 35 lb. and

50 lb. weights. They were instructed to adjust the fre-
quency of lift until they reached the maximum that they
could maintain without excessive fatigue. Three height
levels were used: floor to knuckle, knuckle to shoulder,
and shoulder to reach. Negative correlations were found
between selected frequency of lift and subject's height
and weight. The maximum frequency and workloads selected
by male workers are shown in Table 17.

Ayoub, et al. (1978) studied the effect of frequency
on the weight lifted at different height levels using a
psychophysical approach. Table 18 gives the means of
maximum weights acceptable to male and female industrial
workers. For males, there was a continuous decrement in
the maximum acceptable weight of lift for all six height
levels as the frequency increased. However, between
intermediate levels of frequency, the slope was not very
steep. For females, this trend was evident only for the
floor to shoulder and floor to reach heights. The decre-
ment was continuous for all other heights on a large
sample size of industrial workers (146 males and females).

Effect of Frequency: Summary

Table 19 gives a comprehensive summary of the effects
of frequency effect on amount of weight lifted in the
form of regression equations (Ayoub, et al., 1978). In
order to obtain the maximum acceptable weight of lift
for a given frequency, (ranging from 2 to 8 lifts/min.)
at a given height level, interpolate any frequency factor
into any of the given equations.

Effect of Box Size: Literature Review

So far, research efforts have primarily concentrated
on the safety of the load with very little importance
associated with protecting the worker against injuries.
According to Herrin, et al. (1974), the need for research
in the load dimension area is substantiated in the tech-
nical literature, with the research criteria based on

TABLE 17
Maximum Frequency and Workloads
Selected by Male Industrial
Workers While Lifting
Continuously*

Lift Range	Weight of object (pounds)	Frequency (lifts/min)	Mean Workload (ft.-lb./min.)
Shoulder to arm reach	50	4.4	374
	35	5.9	342
Knuckle to shoulder	50	5.3	454
	35	7.1	413
Floor to knuckle	50	3.8	317
	35	4.2	244

Snook and Irvine, 1968

*The Box dimensions were 19"L x 13.5"W x 5.5"H
Frequency of lift was selected by subject (Psychophysical
method).

TABLE 18

Mean and Standard Deviation of the Maximum Weights (lbs.)
Acceptable to Male and Female Industrial Workers for
Different Frequencies (lifts/min.), Using Three Box
Sizes in the Sagittal Plane - 12 in., 18 in., and
24 in., With Handles*

Height of Lift	Sex	Frequency=2		Frequency=4		Frequency=6		Frequency=8	
		Mean	Std. Devia.	Mean	Std. Devia.	Mean	Std. Devia.	Mean	Std. Devia.
Floor to Knuckle	Male	60	18	57	17	55	16	52	17
	Female	30	6	32	8	29	7	30	6
Floor to Shoulder	Male	50	10	48	11	47	12	44	14
	Female	30	7	27	6	26	8	26	6
Floor to Reach	Male	48	13	44	12	43	8	36	9
	Female	27	5	25	6	24	5	24	4
Knuckle to Shoulder	Male	56	14	52	15	52	15	48	14
	Female	30	7	27	5	30	5	25	7
Knuckle to Reach	Male	50	12	44	9	42	8	38	9
	Female	26	6	26	5	26	4	24	5
Shoulder to Reach	Male	43	10	42	11	39	11	36	9
	Female	25	5	23	4	23	3	24	5

Ayoub, et al. (1978)

*Box dimensions were (width x height x Length): 12"x7"x12",
12"x7"x18", and 12"x7"x24".

TABLE 19

Regression Equations of Frequency (lift/min)
Effect on Weight (lbs.) Lifted*

Sex	Height Level	Regression Equation
Male	Floor to knuckle	Weight lifted = 61.96 - 1.19 (frequency)
Female	Floor to knuckle	Weight lifted = 30.81 - 0.09 (frequency)
Male	Floor to shoulder	Weight lifted = 51.79 - 0.91 (frequency)
Female	Floor to shoulder	Weight lifted = 30.11 - 0.57 (frequency)
Male	Floor to reach	Weight lifted - 51.64 - 1.79 (frequency)
Female	Floor to reach	Weight lifted = 28.13 - 0.63 (frequency)
Male	Knuckle to shoulder	Weight lifted = 57.49 - 1.14 (frequency)
Female	Knuckle to shoulder	Weight lifted = 31.21 - 0.68 (frequency)
Male	Knuckle to reach	Weight lifted = 52.91 - 1.85 (frequency)
Female	Knuckle to reach	Weight lifted = 26.72 - 0.26 (frequency)
Male	Shoulder to reach	Weight lifted = 46.45 - 1.28 (frequency)
Female	Shoulder to reach	Weight lifted = 24.26 - 0.15 (frequency)

*Ayoub, et al. (1978)

61

accepted and well developed methods.

Unlike the load characteristics, the dimensions of the load have received very little attention. Since there are so many shapes possible, it is difficult to account for all of them. For this reason they have not been considered as variables by most researchers. Garg (1976) has assumed that the dimensions of the load are not major variables affecting the metabolic cost of lifting, although he does concede that there will be some effect.

Badger, et al. (1972), in a report on the prevention of low back pain in the industrial work force, have recommended that further research be carried out using this task characteristic. The Ergonomics Guide to Manual Lifting (1970) has considered the size of the load as one of the task variables and recommended, without substantiation, that it be taken as a significant hazard factor in evaluating work situations concerning manual materials handling.

Drury and Pfeil (1973) have indirectly presented the effects of load dimensions on lifting capacity. In their experiment, they used a 20 in. cube as the lifting object, as this was very difficult to lift using any kind of lifting technique. It appeared that the non-compact objects used in the experiment allowed about 60 percent of the lifting capacity of that of compact objects (8.5 in. x 19 in. x 19 in.). The lifting capacity used was the one quoted by ILO (1964) and Davies (1972) for the compact objects. These observations were further confirmed by using the equal-moment formula developed by Tichauer (1971).

McConville and Hertzberg (1968) examined the interaction of two variables (weight and width) of one handed, symmetrical boxes. The maximum weight of the box that subjects were able to lift varied linearly with the width of the box. They found that the maximum weight that 95 percent of the population would be able to lift, but not

necessarily carry, could be expressed by a linear equation:

$$Y = 60 - X$$

where Y is the weight (in lbs.) of the package to be lifted
and X is the width (in inches). According to the authors,
the numerical value of the above expression provides a
recommended upper limit on the design of industrial or
military equipment.

As is evident from above, if the container or package
width is increased without changing the load of the object,
the nature of the task may change from light to medium to
heavy, and consequently may increase the hazard risk.

Woodson and Conover (1964) have suggested maximum
weights for different size containers to be lifted to
specific heights They, however, have provided no justi-
fication or basis for recommending a particular size box
for a given weight of the object.

Tichauer (1971) presented the concept of weight/bulk
ratio and attempted to quantify the physical stress to which
anatomical structures are subjected. According to him,
lifting stress should not solely depend on the weight of
the object, but rather on the moment exerted on the verte-
bral column. The moment concept implies that a bulky
object must be "physiologically heavier" than a compact
object of the same weight. He has demonstrated that the
muscle stress produced as a result of lifting an object
is proportional to the moment exerted on the lumbar spine
rather than to the weight of the object being held. He
also established that the weight/bulk ratio of the object
handled is a major determinant of the severity of a lifting
task. He recommends that 'quantitative relationships'
between weight/bulk ratios and physiological work stress,
as well as critical weight/bulk ratios affecting tolerance
be established at higher levels of confidence through
further experimentation. In his opinion, "weight limita-
tions on lifting legislated or recommended by governmental,

intergovernmental, and private bodies are often irrelevant and valueless because they do not consider weight/bulk ratio of the object handles...". The moment concept is expressed in the following equation developed by Tichauer:

$$(8 + 0.5L) \, (W) = ME$$

   where:

   W = the weight of the load,

   L = the length in inches of one side of a cube of uni-
        form density, and

   ME = the moment exerted on the vertebral column.

   According to McFarland (1969), bulky objects (i.e., 30 in. on a side) should not exceed 20 lbs., with the center of gravity not more than 20 in. away from the carrier's body. This is more a statement than experimental verification, although according to Tichauer, (1971), this constitutes 'heavy' work.

   Aghazadeh (1974) attempted to verify the moment rela- tionship developed by Tichauer (1971). He concluded that the acceptable weight of lift is linearly related to the box size (where the box size is the box dimension perpen- dicular to the frontal plane of the body). This conclusion is identical to the one made by Tichauer (1971). Aghazadeh (1974) recommended that "the effects of height, width, and handle of container in relation to the amount of weight should be analyzed and studied."

   Kellerman and Van Wely (1961) have attempted to deter- mine the optimum shape and size of a container for use by the flower bulb industry. In their study, they first determined the optimal weight and then the optimal size. They considered the same weight with different size con- tainers. In short, the weight/bulk ratio was not considered. It was found that for the optimal size determined by them, the optimal weight was 38.5 lbs.

   Ayoub (1976) considered a different approach and attempted to show that the design of containers is a problem

of mechanics. He maintains that the use of optimization techniques for the design has a lot more potential. He also believes that the application of the probabilistic approach is possible.

Martin and Chaffin (1972) showed that the lifting force decreased linearly with an increase in length (length in the sagittal plane).

Tichauer, et al. (1973) demonstrated experimentally that it is not easy to hold large boxes weighing 10 and 15 lbs.- weights which are not considered severe by current lifting standards. The response to physical work stress is met by a change in the posture. He concluded that lifting when performed by tall, thin women may lead to lower back trauma because of their limitations for postural adjustments.

Tichauer, et al. (1973) stressed the need for further research to provide adequate hard data and to establish criteria for package and container design. Furthermore, they suggested that these efforts should be broadened and deepened in order to quickly produce reliable data related to biomechanical parameters of package design. Regarding the general criteria for the design of packages and containers, they recommend compliance with two different sets of specifications; namely, technical specifications and ergonomics specifications. Technical specifications refer to conforming to the dimensional standards, while the ergonomics specifications refer to making the container handling less stressful and safe.

It can be safely deduced from the foregoing research that bulky and light loads are less safe to handle than compact and heavy loads. Furthermore, Tichauer, et al. (1972) suggested that any lifting task imposing a sagittal bending moment upon the lumbar spine exceeding substantially 250 lb.-in. consitutes heavy work; and that such a task must be carefully designed in order to avoid injury. But presently, no reliable information about the optimality of shape or container configuration is available.

Most of the research results reported in this country
are concerned with lifting and not with container and
package dimensions which are very much a part of maintaining
occupational safety and health.

Ayoub, et al. (1978) studied the effect of box size on
the lifting ability of male and female industrial workers
using a psychophysical approach. The box size in this study
was defined as the distance of the box's center of gravity
from the spine of the subject in the sagittal plane. Three
box sizes were used: 12 in., 18 in., and 24 in. Six lift-
ing height levels were used:

1. floor to knuckle height,
2. floor to shoulder height,
3. floor to reach height,
4. knuckle to shoulder height,
5. knuckle to reach height, and
6. shoulder to reach height.

Figures 3 through 8 show the effects of box size for the
six height levels for males and females. For the sequences
floor to knuckle height, floor to reach height, and knuckle
to shoulder height, the maximum acceptable weight of lift
for the male subjects decreased. This decrement was most
significant for the floor to knuckle height (about 10 lbs.).
For the female subjects, a similar effect was observed for
all height levels except for the knuckle to reach height,
in which case the maximum acceptable weight first decreased
and then increased slightly.

In the floor to shoulder height and knuckle to reach
height for males, the maximum acceptable weight of lift
first increased and then decreased. For the shoulder to
reach height, it decreased very slightly and then increased.

The maximum decrement due to change in the box size for
female subjects was about 4 lbs. for the floor to knuckle
height. For males, the maximum decrement was also observed
at this height level. Table 20 gives regression equations
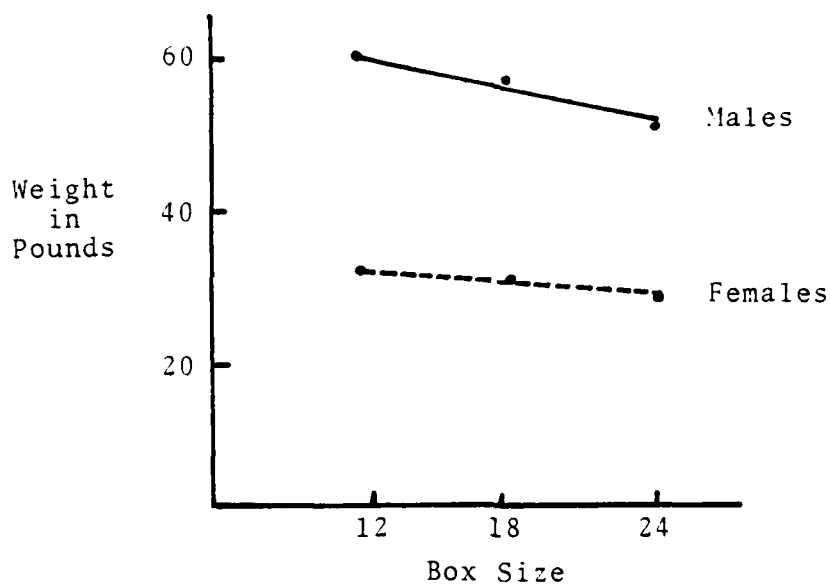
Figure 3:   The Effects of Box Size for Males
and Females for Height Level 1
(floor to knuckle).
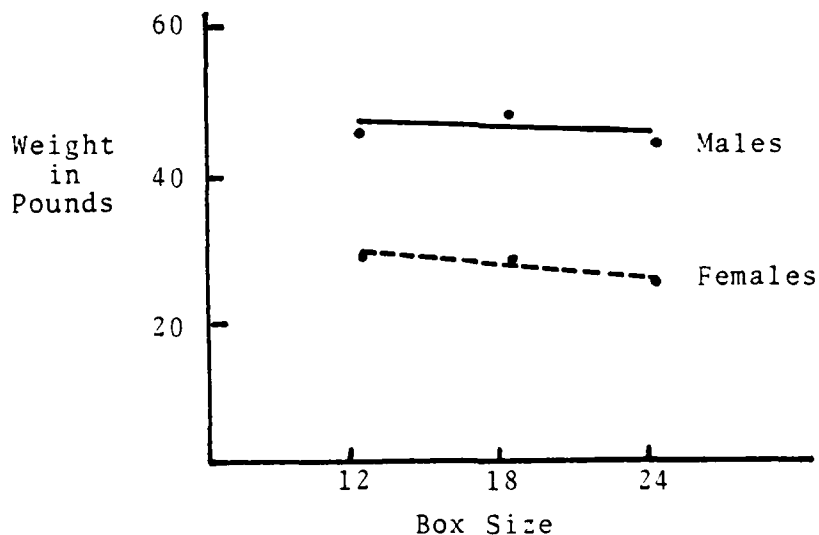
Figure 4:   The Effects of Box Size for Males
and Females for Height Level 2
(floor to shoulder).
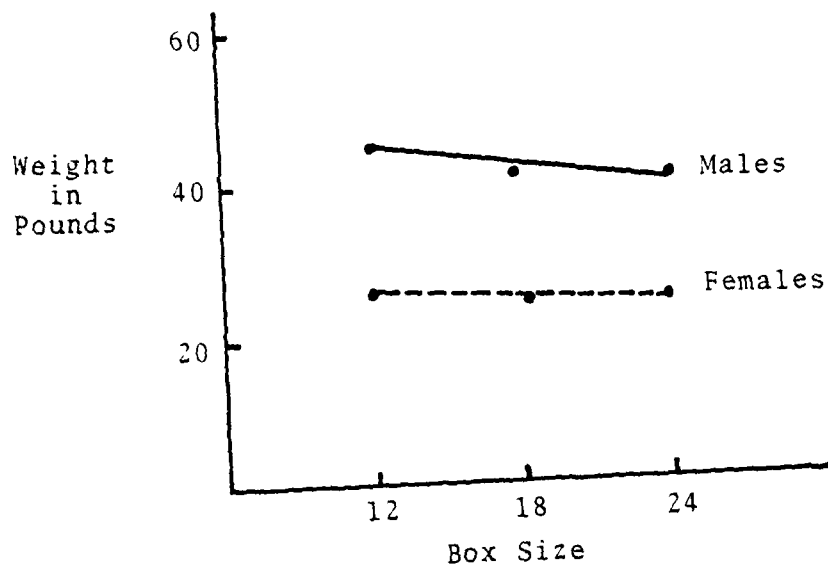
Figure 5: The Effects of Box Size for Males and Females for Height Level 3 (floor to reach).
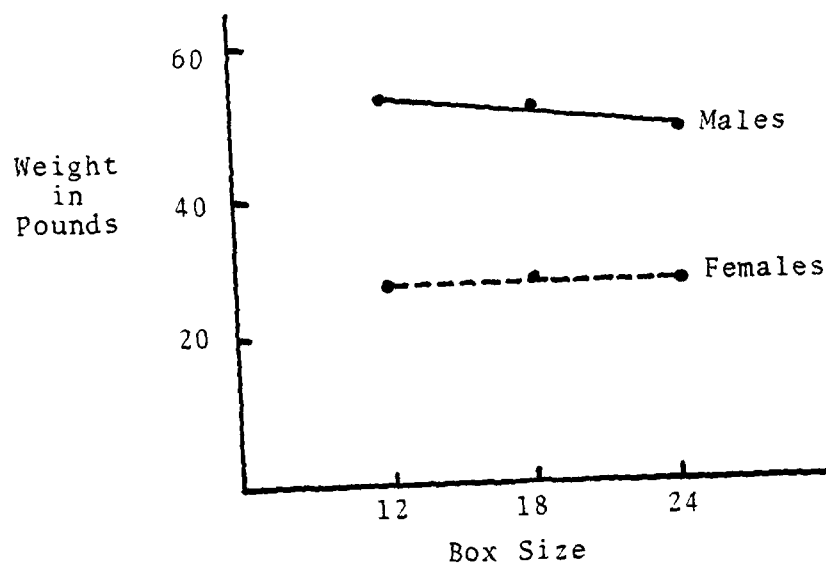
Figure 6: The Effects of Box Size for Males and Females for Height Level 4 (knuckle to shoulder).
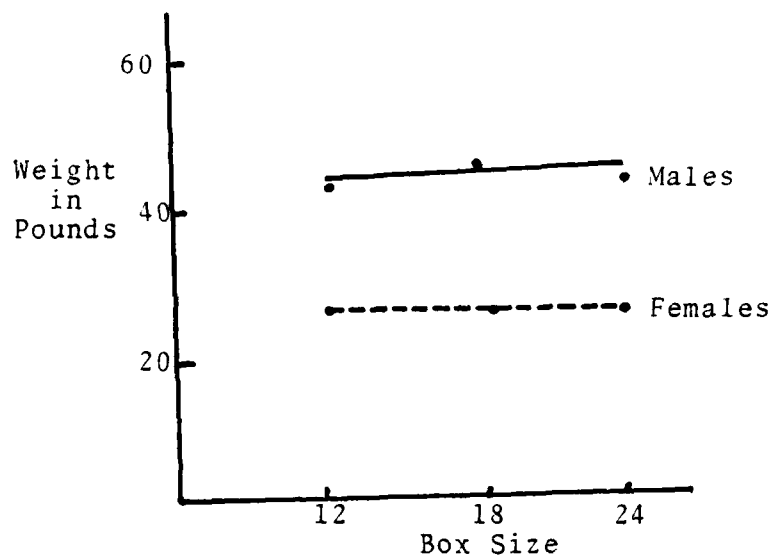
Figure 7: The Effects of Box Size for Males
and Females for Height Level 5
(knuckle to reach).
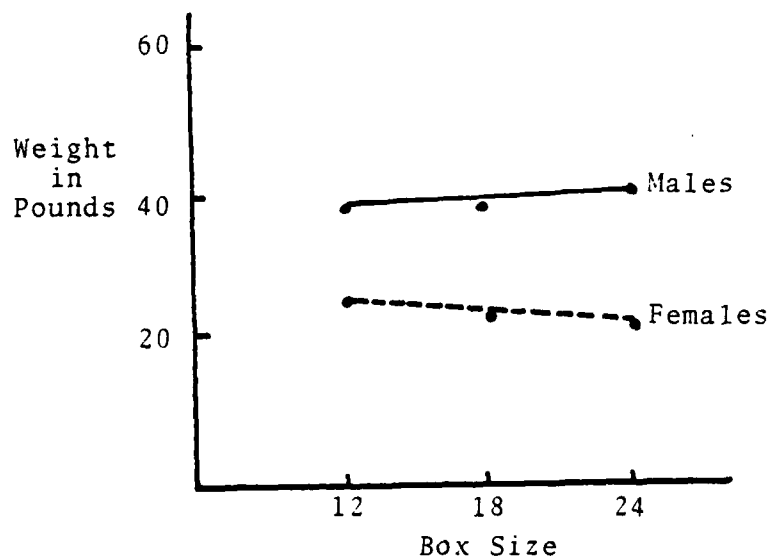
Figure 8: The Effects of Box Size for Males
and Females for Height Level 6
(shoulder to reach).

TABLE 20

Regression Equations for Box Size*(in.) Effects
on Amount of Weight (lbs.) Lifted

Sex	Height Level	Regression Equation
Male	Floor to knuckle	Weight lifted = 70.57 - 0.808 (box size)
Female	Floor to knuckle	Weight lifted = 36.09 - 0.323 (box size)
Male	Floor to shoulder	Weight lifted = 48.48 - 0.093 (box size)
Female	Floor to shoulder	Weight lifted = 33.03 - 0.303 (box size)
Male	Floor to reach	Weight lifted = 49.36 - 0.386 (box size)
Female	Floor to reach	Weight lifted = 27.80 - 0.148 (box size)
Male	Knuckle to shoulder	Weight lifted = 56.83 - 0.285 (box size)
Female	Knuckle to shoulder	Weight lifted = 29.98 - 0.121 (box size)
Male	Knuckle to reach	Weight lifted = 43.24 + 0.0442 (box size)
Female	Knuckle to reach	Weight lifted = 25.59 - 0.004 (box size)
Male	Shoulder to reach	Weight lifted = 37.62 + 0.124 (box size)
Female	Shoulder to reach	Weight lifted = 27.18 - 0.206 (box size)

Ayoub, et al. (1978)

*Box dimensions were (width x height x length): 12"x7"x12", 12"x7"x18",
and 12"x7"x24"

70

for predicting the weight lifted for a specified box size based on the data of Ayoub, et al. (1978).

Effect of Box Size: Summary

Most researchers agree on the fact that increasing the size of the box in the sagittal plane is associated with a linear decrease in the amount of weight lifted by a subject.

The data of Ayoub, et al. (1978) in Figures 3 through 8 were utilized for summarizing the effect of box size on the amount of the weight lifted, as it was the most complete data set available at present, covering a wide range of lifting heights. It was also based on a large sample size of industrial workers (146 male and female).

PUSHING AND PULLING

Considerably less data were found for pushing and pulling than for lifting. Thus this category is only divided into the data for strength norms and capacity norms.

Strength Norms: Literature Review

Troup and Chapman (1969) observed the maximum steady pulling force (for 1 sec.) exerted by 132 male and 98 female subjects. The forces were measured in sitting and standing positions using a strain-gauge dynamometer. It was found that forces were greater in the sitting position than in the standing position. However, the forces transmitted by the erector spinae were of similar magnitude for sitting and standing. When standing the lumbar spine is extended and the erector spine shortened; this provides a relatively greater mechanical advantage than a sitting posture. In the sitting position, the smaller mechanical advantage is compensated by a shorter distance between the pelvis and the upper limbs resulting in a turning movement similar to when standing.

Ayoub and McDaniel (1974) studied the maximum isometric pushing and pulling forces exerted by 35 males and 11 females as a function of foot and hand placement. Foot placement was defined as the distance of the rear foot away from the vertical plane of the handle, and the hand placement was predicated upon the height of the handle above the floor.

The effects of bar height and foot position on the horizontal pushing and pulling forces are summarized in Tables 21 and 22 (the values presented in these tables were obtained by interpolating from the graphs given by Ayoub and McDaniel, 1974). It was found that optimal pushing forces were generated when the hands were placed at 50 percent of the subject's reach height on the object to be pushed, and, the feet were placed at 70 percent of the worker's reach height from the vertical plane. For pulling forces, it was found that optimal forces were generated when the bar height (i.e., the gripping surface) was at 70 percent of the worker's shoulder height, and the foot distance 10 percent of the worker's height.

Subject body weight also had a significant effect on pushing and pulling forces. Its interaction with both foot distance and bar height resulted in considerably higher pushing forces at high bar height and larger foot distance, and higher pulling forces at the shortest foot distance and lowest bar height. The ratio between the horizontal and resultant pushing forces, for both males and females, was greatest at bar heights of about 70 and 80 percent of the shoulder height (or 50 percent reach height). The ratio was lowest for a foot distance of 80 percent of the reach height.

Kroemer (1974) measured the maximal isometric (static horizontal push forces which could be exerted in many common working conditions. Seventy-three male subjects were used. Of these, 45 participated in the experiments with wall or footrest, 28 took part in the experiment with slippery floors. The experiment simulated all kinds of body supports and body postures which might occur in daily life when one has to exert

TABLE 21
Effect of Bar Height and Foot Position On
Horizontal Pushing Force (lbs.)
For Males and Females

MALES

Bar Height* (% Reach Height)	Foot Distance* (% Reach Height)				
	30	40	50	60	70
30	50	55	75	94	110
40	48	64	83	99	130
50	45	67	90	103	132
60	40	61	84	122	150
70	37	67	95	127	137
80	52	86	123	100	---

FEMALES

Bar Height* (% Shoulder Height)	Foot Distance* (% Reach Height)				
	50	60	70	80	90
60	40	44	50	56	59
70	40	50	51	59	61
80	38	42	54	59	70
90	38	46	50	61	78
100	40	43	56	60	78

Ayoub and McDaniel (1974)

*Bar height is height of the handle above the
floor. Foot distance is the distance of the
rear foot away from the vertical plane of the
handle. Both of these parameters are reported
in percent of the subject's shoulder height or
reach height.

TABLE 22
Effect of Bar Height and Foot Position On
Horizontal Pulling Force (lbs.)
For Males and Females

MALES

Bar Height* (% Reach Height)	Foot Distance*(% Reach Height)				
	30	20	10	0	-10
30	57	82	106	135	154
40	63	77	90	105	116
50	52	65	78	85	95
60	49	60	65	70	75
70	45	48	52	55	58
80	35	40	59	46	45

FEMALES

Bar Height* (% Shoulder Height)	Foot Distance*(% Reach Height)				
	30	20	10	0	-10
60	51	63	70	81	89
70	50	66	71	80	85
80	42	56	63	70	75
90	40	53	56	63	65
100	41	45	50	52	55

Ayoub and McDaniel (1974)

*Bar height is the height of the handle above the floor. Foot distance is the distance of the rear foot away from the vertical plane of the handle. A negative value of the foot distance means the feet are on the other side of the handle. Both of these parameters are reported in percent of the subject's shoulder height or reach height.

a maximal horizontal push force. Subjects were instructed to maintain a maximal horizontal push force steadily over the 5 second period. The force exerted increased during the first second, then stayed constant, and then dropped during the last second. The mean force applied during the third second was used.

Table 23 shows the lowest horizontal static forces that healthy male adults, under common working conditions, should be able to exert intermittently and for short periods of time. It was concluded from Kroemer's study (1974) that body posture, body support, and the chain of body members through which the force was transmitted had significant effects on the amount of force exerted. Body weight, alone or in combination with the body size, was not very useful in predicting force output. A physically strong subject may be able to exert only weak push or pull forces due to lack of body support.

The force (for each operator) given in Table 23 can be added to obtain the combined push capacity of up to three people. Beyond this, the force added does not increase proportionately and consequently cannot be directly added. In conjunction with the study by Snook, et al. (1970), it can be concluded from Kroemer's (1974) study that 90 percent of the male workers should be able to exert an initial two-handed push force of about 220 N and a continuous push force of about 110 N for distances up to 98.4 ft.

Strindberg and Peterson (1972) measured the force required to start a trolley rolling. It was found that a person could exert, on the average, a pushing force of about 80 percent of his body weight.

Caldwell (1964) studied the body position, strength, and endurance of manual pull. Ten male subjects were used (mean weight 171 lbs, mean height 68.9 in., age range 22-39 years). Strength (response) and endurance were measured for 20 different body positions which were combinations of five elbow angles (95°, 110°, 125°, 140° and 155°) two thigh angles

TABLE 23

Least Horizontal Push Forces That Males Should be Able to Exert Intermittently and for Short Periods of Time

Force	Applied With	Condition (μ: coefficient of static friction)
100N(25 lbs) Push or Pull	Both hands or one shoulder or the back	With low traction $.2 \leq \mu \leq .3$
200N(45 lbs) Push or Pull	Both hands or one shoulder or the back	With medium traction $\mu \sim .6$
250N(55 lbs) Push	One hand	If braced against a vertical wall (20-60 in) from and parallel to the push panel
300N(70 lbs) Push or Pull	Both hands or one shoulder or the back	With high traction $\mu \geq .9$
500N(110 lbs) Push or Pull	Both hands or one shoulder or the back	If braced against a vertical wall (20-70 in) from and parallel to the panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)
750N(165 lbs) Push	The back	If braced against a vertical wall (23-43 in) from and parallel to the push panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)

Kroemer (1974)

77

(0° and 20°); and two knee angles (110° and 150°). Each subject was required to pull maximally for a period of 8 seconds for the strength test. For the endurance test, the subject was asked to apply 80 percent of the maximal pull for as long as possible. A green light, which would turn on at 80 percent pull force, was used to assist subjects in maintaining this pull force.

An increase in the knee angle resulted in an increase in strength. The same was true for an increase in elbow angle. Trunk stabilization improved with an increase in the thigh angle. These responses occurred during endurance tests also. It was concluded that a change in body position, control placement, or body stabilization which increased strength would reduce the effort required to maintain a given force under control. In addition, the endurance of the holding response would be proportionately increased. In other words, static strength could be used to predict static endurance with reasonable confidence.

However, Smith and Edwards (1968) indicated that muscular endurance (dynamic endurance) may not be predicted from static strength. Forty male students participated in this study. A grip dynamometer was used to record static strength, static (isometric) endurance, and dynamic (isotonic) endurance. Subjects were given two training sessions each for 14 weeks. A poor correlation was found between strength and pre- and post- training isometric and isotonic endurance.

Strength Norms: Summary

The study by Ayoub and McDaniel (1974) will be used to summarize the research dealing with pushing and pulling forces. Presently, it is the most comprehensive study in this area. Tables 21 and 22 give a summary of the data. However, it should be noted that the data in these tables is for pushing and pulling forces applied with both hands. For other modes of application of pushing and pulling forces, Table 23, which is based on Kroemer (1974) should be consulted.

Capacity Norms: Literature Review

Snook, et al. (1970) and Snook and Ciriello (1974) also studied pushing and pulling capacities, along with lifting and lowering capacities described earlier. The heights used for pushing and pulling approximated the handle heights "commonly" found in industry. The pushing and pulling tasks were simulated on a specially constructed treadmill which was powered by the subject as he or she pushed or pulled against a horizontal bar. Force was the dependent variable and was varied by controlling the resistance of the treadmill belt by varying the amount of electric current flowing into a magnetic clutch. The subjects were encouraged to make force adjustments by starting them with either a very light or very heavy force.

Capacity Norms: Summary

The results of the foregoing studies were summarized by Snook (1978). Tables 24 through 26 present the maximum acceptable forces for pushing and pulling for male and female industrial workers. Only one pulling distance is presented, since objects transported over greater distances are usually pushed. It is important to note that not all of the data presented in Tables 24 through 26 were generated via experimentation. To fill in some gaps that have not been studied, Snook made some assumptions based on his current experimentation (e.g. some of the intermittent task frequencies between 1 minute and 8 hours).

CARRYING

Literature Review

Parts of the studies by Snook, et al. (1970) and Snook and Ciriello (1974) were to determine the maximum rate of walking (miles/hr) acceptable to male and female workers. Rate was used as a dependent variable in the walking tasks. For carrying tasks, subjects determined their own work loads at different walking speeds. The tote box (19 in. x 13.5 in.

78

TABLE 24

THE MAXIMUM ACCEPTABLE FORCES OF PUSH FOR MALES

Vertical Distance (in)*		100 ft. Push one push every					150 ft. Push one push every					200 ft. Push one push every				
		1	2	5 min.	30	8 hr.	1	2	5 min.	30	8 hr.	2	3	5 min.	30	8 hr.
INITIAL FORCE																
57"	x̄	51	55	64	68	73	48	51	60	64	68	46	46	53	57	62
	σ	12	15	15	17	17	14	14	15	19	19	14	12	15	17	17
37"	x̄	57	64	73	79	84	55	59	68	73	77	53	53	62	66	70
	σ	14	15	17	17	19	15	14	17	21	22	15	14	17	19	19
25"	x̄	46	55	62	68	70	44	51	57	62	66	44	46	53	57	59
	σ	10	14	15	15	17	12	12	17	19	21	12	12	14	15	17
SUSTAINED FORCE																
57"	x̄	29	35	40	42	46	26	33	37	40	44	26	29	31	35	37
	σ	7	9	10	12	12	7	9	9	10	10	7	7	9	9	10
37"	x̄	29	33	40	42	46	29	33	37	40	42	26	29	31	35	37
	σ	9	9	9	10	10	7	9	9	10	12	9	9	9	9	9
25"	x̄	29	33	37	42	44	29	31	35	37	42	29	29	31	33	35
	σ	9	9	9	9	10	7	9	9	10	10	7	9	7	9	10

Snook (1978)

*From floor to hands

TABLE 25

THE MAXIMUM ACCEPTABLE FORCES OF PUSH FOR FEMALES

Vertical Distance (in)*		100 ft. Push one push every					150 ft. Push one push every					200 ft. Push one push every				
		1	2	5 min.	30 min.	8 hr.	1	2	5 min.	30 min.	9 hr.	2	3	5 min.	30 min.	9 hr.
INITIAL FORCE																
53"	x̄	37	40	44	48	51	35	35	42	46	48	33	33	37	39	44
	σ	7	10	9	9	10	5	7	7	7	9	5	5	7	9	7
35"	x̄	42	46	51	55	58	40	42	48	51	55	37	37	42	46	48
	σ	9	10	10	10	10	7	7	7	10	9	7	7	9	9	9
22"	x̄	33	40	44	48	51	31	35	42	44	46	31	33	37	40	42
	σ	7	9	9	9	9	7	7	9	9	9	5	5	5	7	9
SUSTAINED FORCE																
53"	x̄	24	26	33	35	40	20	24	29	31	33	19	22	24	26	29
	σ	3	5	5	7	7	5	5	5	5	5	3	5	5	5	5
35"	x̄	24	26	33	35	27	22	24	29	31	33	20	22	24	25	29
	σ	5	5	5	7	7	3	5	5	5	5	5	5	3	5	5
22"	x̄	24	26	31	35	37	22	24	26	29	31	22	22	22	24	26
	σ	5	3	5	3	7	3	5	5	5	7	3	3	5	5	5

Snook (1978)

*From floor to hands

80

TABLE 26

THE MAXIMUM ACCEPTABLE PULLING FORCES FOR MALES AND FEMALES

Vertical Distance (in)*		7 ft. pull (initial forces) one pull every							7 ft. pull (sustained forces) one pull every						
		6 sec.	12	1 min.	2	5	30	8 hr.	6 sec.	12	1 min.	2	5	30	8 hr.
Male 57"	x̄	42	43	55	57	64	66	68	26	35	42	42	46	48	51
	σ	12	14	14	14	15	15	17	7	10	12	14	15	15	15
Female 53"	x̄	42	42	42	44	48	51	53	31	31	33	33	37	37	40
	σ	10	12	10	9	10	12	12	9	9	9	9	9	10	10
Male 37"	x̄	59	68	77	79	88	92	97	33	44	55	57	62	64	66
	σ	15	17	17	19	21	21	22	9	14	17	15	19	21	21
Female 35"	x̄	57	59	59	62	68	70	75	40	42	42	44	48	51	51
	σ	15	15	12	12	15	15	15	12	10	12	12	12	12	15
Male 25"	x̄	68	77	86	90	99	103	108	35	48	59	59	66	68	70
	σ	17	19	21	21	24	24	26	10	14	17	19	19	21	22
Female 22"	x̄	64	66	66	68	77	79	84	40	44	44	44	51	53	55
	σ	17	17	15	15	17	19	19	12	12	12	12	14	14	14

Snook (1978)

*from floor to hands

x 5.5 in) was carried for a distance of 7 ft., 14 ft., and 28 ft. The results of these studies are in Tables 27 and 28.

Summary

The only two studies that are available dealing with carrying are Snook, et al. (1970) and Snook and Ciriello (1974). Therefore, Tables 27 and 28 will be used to summarize the data.

TABLE 27
Distribution of Maximum Work Loads (ft.-lb./min.) Acceptable to Male and Female workers while carrying a 19"Lx13.5"Wx5.5"H Tote Box at Elbow Height*

Distance Carried (ft.)	Sex	Mean	Std. Devia.	Percent of Population				
				95	75	50	25	5
7	Ind. men	2485	645	1423	2051	2485	2919	3546
	Ind. women	2198	458	1445	1897	2198	2499	2951
	Housewives	1418	359	827	1181	1418	1654	2009
14	Ind. men	3066	865	1643	2484	3066	3648	4488
	Ind. women	2649	662	1560	2213	2649	3084	3737
	Housewives	1596	384	963	1343	1596	1849	2228
28	Ind. men	3070	736	1859	2575	3070	3565	4281
	Ind. women	2744	432	2033	2460	2744	3028	3455
	Housewives	1733	388	1094	1477	1733	1988	2372

Snook, et al. (1970)

Snook and Ciriello (1974)

*Assuming a normal distribution

TABLE 28

Distribution of Maximum Weights (lbs.) Acceptable to Male and Female Workers While Carrying a 19"Lx13.5"Wx5.5"H Tote Box at Elbow Height*

Distance Carried (ft.)	Sex	Mean (lbs.)	Std. Devia.	Percent of Population				
				95	75	50	25	5
7	Ind. men	58	14	35	49	58	67	81
	Ind. women	38	8	25	33	38	43	51
14	Ind. men	51	12	32	43	51	59	70
	Ind. women	38	8	25	33	38	43	51
28	Ind. men	45	10	28	38	45	52	62
	Ind. women	34	7	22	29	34	39	46

Snook, et al. (1970)

Snook and Ciriello (1974)

*Assuming a normal distribution

84

Comparison of Load Limits Based on the
Biomechanical, Physiological, and
Psychophysical Criteria

A direct comparison of the physiological, biomechanical, and
psychophysical methods for establishing lifting capacity is diffi-
cult because of the procedural differences among the relevent
studies. However, an examination of the data per se does address
the following questions: 1) under what criterion are there high-
er acceptable weight limits; and 2) under what conditions are the
three criteria similar.

A comparison of the data generated by experimentation based
on the three criteria revealed the following:

1. For infrequent lifting, the maximum permissible weight
   of a load as determined by psychophysical methods is
   less than the recommended weights based on the biomechan-
   ical model. In other words, the acceptable weight limits
   based on muscle strength testing (Martin & Chaffin, 1972)
   are usually higher than those based on the psychophysical
   model (Snook, 1978; Ayoub, et al., 1978; Snook & Irvine,
   1967). However, the psychophysical data also indicate
   that lifting capabilities increase if the time interval
   between lifts increases. Snook (1978) found that the
   average acceptable weights for women were 46 lbs. and
   57 lbs. for 120 second and 300 second intervals, respec-
   tively. These lifting capabilities were comparable to
   the lifting capabilities of 50 percent of the women under
   the biomechanical criterion (Martin & Chaffin, 1972).
2. For repetitive lifting, the maximum acceptable weights
   based on the psychophysical criterion are lower at lower
   lifting frequencies and higher at higher lifting fre-
   quencies than those weights based on the physiological
   criterion.

Tables 29 and 30 present data based on the three aforemen-
tioned criteria. However, the data do not represent a direct com-
parison of the criteria, for procedural differences among the

TABLE 29

ACCEPTABLE WEIGHT (lbs.) BASED ON PSYCHOPHYSICAL AND
PHYSIOLOGICAL CRITERIA FOR FLOOR TO KNUCKLE HEIGHT

Criteria	Reference	Method of Lift	Lifting Frequency (lifts/min)	Acceptable Weight to 50% Male Population (lbs)
Psycho-physical	Ayoub, et al. (1978)	Free style lift	4.0	64
			6.0	63
			8.0	61
		Stoop lift	4.0	73
			6.0	35
			8.0	24
Physio-logical	Garg (1976) (estimate of weight based on metabolic criteria)	Squat lift	4.0	48
			6.0	18
			8.0	7

TABLE 30

LIFTING CAPABILITIES OF MALE AND FEMALE POPULATIONS
BASED ON BIOMECHANICAL MODELING (MARTIN AND CHAFFIN, 1972)

Horizontal Distance (in)	Vertical Distance (in)	Lifting Capability (lbs) 50% Population Percentile	
		Male	Female
12	12	112	51
12	59	103	24
24	12	53	20
24	59	46	11
35	12	11	0
35	59	15	0

pertinent studies makes such a comparison difficult. It is recommended that further research be conducted to fill the extant gaps which preclude a true comparison of the three criteria.

Comparison of pushing-pulling and carrying limits based on the foregoing criteria is presently not possible; experimentation in pushing-pulling and carrying has basically followed the psychophysical model. Obviously, further research should strive to generate data representing pushing-pulling and carrying limits based on the physiological and biomechanical models.

Recommendations for Mil-Std-1472B Revision

The preceding literature review and experimental results were used as the basis for recommending changes in Mil-Std-1472B for MMHA. The following is recommended for inclusion in Mil-Std-1472B for the MMHA Section.

5.9.11.3.1.1 <u>Limits</u>. The weight limits in Table 1 shall be used in determining the design weight of items requiring one-man lifting. For two-man lifting, the weight limits would be approximately twice the amount of weight prescribed for each condition in Table 1. The weights lifted should adhere to those presented in Table 1. The weight lifted should be reduced as the box size increases in the sagittal plane. The absence of handles on boxes usually results in a 15 percent reduction in the amount of weight lifted obtained from Table 1. The handles or grasp areas should conform to paragraph 5.9.11.5. The weight limits in Table 2 shall be used in determining the design weight of items requiring one-man lowering. In using Tables 1 and 2 to estimate the recommended weight of lift and lower for a particular height of lift, box dimension, and frequency of lift, locate the mean value (in pounds) pertaining to the particular task variables. For example, if a job requires lifting a 12 inch box (length in the sagittal plane) twice every minute from floor to knuckle, the maximum acceptable weight for 50 percent of the male worker is 61 pounds.

5.9.11.3.1.2. <u>Labeling</u>. Items weighing more than the one-man lift values of Table 1 shall be prominently labeled with weight indication and lift limitation (i.e., mechanical or two-man lift). Where mechanical or power lift is required, hoist and lift points shall be provided and clearly labeled.

5.9.11.3.2. <u>Carrying</u>. The limits in Table 3 shall be used in determining the weight of a 19"x13.5"x5.5" tote box. The weight limits shall correspond to the presented distances that a load is to be carried (i.e. 7, 14, 28 feet). It should be noted that those lifting limits prescribed in Table 1 (paragraph 5.9.11.3.1.1.) are not applicable to tasks where carrying the load is involved.

TABLE 1

Mean and Standard Deviation of the Maximum Recommended Weight of Lift
(lbs.) for Male and Female Workers

Height of Lift	Box Dimension in the Sagittal Plane		MALE WORKERS						FEMALE WORKERS					
			_____ Frequency of Lift/min _____											
			1	2	4	6	8	12	1	2	4	6	8	12
Floor to Knuckle	12	x̄	67	61	53	49	46	39	44	41	35	31	29	25
		σ	19	21	15	18	17	12	7	3	7	8	7	7
	18	x̄	59	57	52	48	43	34	39	30	28	27	26	23
		σ	17	19	21	13	14	9	7	7	11	7	5	5
	24	x̄	53	51	47	53	39	31	34	28	27	27	25	21
		σ	17	15	17	11	18	9	7	5	6	5	6	5
	32	x̄	52*	53	48	45	42	36*	29*	29	29	28	28	27*
		σ	15	14	12	13	14	14	7	7	3	8	4	2
Floor to Shoulder	18	x̄	54*	55	51	49	47	43*	32	32	30	28	26	22*
		σ	7	7	13	11	15	10	6	6	7	10	5	4
	24	x̄	51*	51	59	47	45	41*	30	29	28	26	25	22*
		σ	11	11	10	8	14	12	6	6	4	5	8	7
Floor to Reach	12	x̄	48*	47	45	42	40	35*	28*	27	26	25	24	21*
		σ	11	11	15	7	8	6	5	5	6	6	4	6
	18	x̄	57*	53	47	40	33	19*	29	28	27	25	24	22*
		σ	14	13	13	9	8	4	5	5	5	4	4	4
	24	x̄	41*	41	59	58	57	54*	27	26	25	24	23	20*
		σ	12	12	8	9	10	8	6	6	7	5	4	5

TABLE 1 (continued)

Mean and Standard Deviation of the Maximum Recommended Weight of Lift
(lbs.) for Male and Female Workers

Height of Lift	Box Dimension in the Sagittal Plane		MALE WORKERS						FEMALE WORKERS					
			1	2	4	6	8	12	1	2	4	6	8	12
								Frequency of Lift/min						
Knuckle to Shoulder	12	x̄	53	51	48	44	41	34	32	31	30	28	26	23
		σ	15	12	16	19	12	9	5	8	5	5	8	3
	18	x̄	59	57	53	49	44	31	29	29	29	28	25	20
		σ	14	16	19	14	12	9	5	8	5	5	7	5
	24	x̄	46	45	42	39	36	31	29	28	26	25	23	19
		σ	14	16	15	19	16	9	5	6	7	6	5	4
Knuckle to Reach	12	x̄	49*	47	43	40	36	29*	28*	28	27	25	24	22*
		σ	15	15	9	11	8	3	3	8	6	5	7	6
	18	x̄	55*	55	48	44	40	31*	26	26	25	25	24	23*
		σ	9	9	8	7	11	10	4	4	5	4	4	4
	24	x̄	54*	52	48	44	40	32*	32	31	29	26	24	19*
		σ	13	13	7	5	7	4	5	5	6	2	5	5
Shoulder to Reach	12	x̄	50	49	46	40	33	24	27	26	24	21	19	14
		σ	15	5	14	12	9	9	3	5	4	4	5	2
	18	x̄	45	41	40	38	35	24	25	24	22	20	17	13
		σ	12	10	12	17	9	5	3	4	5	5	5	5
	24	x̄	44	40	39	38	34	24	26	25	23	22	20	13
		σ	12	11	11	11	9	5	3	5	4	5	3	2

Ayoub, et al. (1978), Snook (1978)

*Data extrapolated from data generated for the other lifting frequencies

91

TABLE 2

Maximum Acceptable Weight (lbs.) of Lower for Males and Females for Different Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift		MALES One Lift Every				FEMALES One Lift Every			
				9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
Floor to Knuckle	29.5"	30"	x	40	57	77	90	26	33	44	53
			o	10	14	21	26	5	5	7	9
		20"	x	40	59	79	95	29	33	46	55
			o	12	15	22	26	5	7	7	9
		10"	x	46	66	90	106	33	37	53	62
			o	16	19	24	29	5	7	9	10
	19.5"	30"	x	46	66	90	66	31	37	53	62
			o	14	19	26	31	5	7	7	10
		20"	x	46	68	92	110	31	40	53	64
			o	15	21	28	33	7	7	10	10
		10"	x	55	77	106	123	37	14	62	73
			o	17	22	31	38	7	9	9	12
	14.2"	30"	x	50	73	99	117	35	42	57	68
			o	15	21	29	34	7	7	9	10
		20"	x	53	75	105	121	35	44	59	70
			o	15	22	1.7	36	7	7	10	12
		10"	x	62	86	1.7	136	42	48	66	79
			o	19	24	54	41	9	9	12	14

Snook (1978)

TABLE 2 (continued)

Maximum Acceptable Weight (lbs.) of Lower for Males and Females for Different Height Levels, Widths of Object, and Vertical Distances

Height of Lift	Width of Object (in. Away from Body)	Vertical Distance (in.) of Lift		MALES	One Lift Every			FEMALES			
			9 sec.	1 min.	5 min.	8 hr.	9 sec.	1 min.	5 min.	8 hr.
	29.5"	30" x	40	48	55	66	29	31	37	42
		o	12	14	15	21	5	5	7	9
		20" x	42	55	64	75	31	33	40	46
		o	14	17	17	22	7	5	9	9
		10" x	51	64	75	88	37	37	48	53
		o	15	19	19	28	9	9	9	10
		30" x	40	48	59	66	29	31	37	42
		o	12	14	17	21	5	5	7	9
Knuckle to Shoulder	19.3"	20" x	42	55	66	75	31	33	40	46
		o	14	17	21	22	7	5	9	9
		10" x	51	64	79	88	37	37	48	53
		o	45	19	22	28	9	9	9	10
		30" x	44	51	64	73	29	35	40	46
		o	12	15	19	21	7	7	9	9
	14.2"	20" x	46	57	72	81	33	55	44	48
		o	14	17	21	24	7	7	9	10
		10" x	55	68	86	97	40	42	51	57
		o	15	21	24	28	19	7	10	12

Snook (1978)

93

1.0

1.1

1.25   1.4   1.6

4.5
5.0
5.6

2.8   2.5

3.2   2.2

3.6

4.0   2.0

1.8

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 3

Distribution of Maximum Weights (lbs.) Acceptable to Male and Female
Workers While Carrying a 19"Lx13.5"Wx5.5"H Tote Box at Elbow Height*

Distance Carried (ft.)	Sex	Mean (lbs.)	Std. Devia.	Percent of Population				
				95	75	50	25	5
7	Ind. men	58	14	35	49	58	67	81
	Ind. women	38	8	25	33	38	43	51
14	Ind. men	51	12	32	43	51	59	70
	Ind. women	38	8	25	33	38	43	51
28	Ind. men	45	10	28	38	45	52	62
	Ind. women	34	7	22	29	34	39	46

Snook, et al. (1970)

Snook and Ciriello (1974)

*Assuming a normal distribution

In using Table 3 to estimate the recommended carrying weights for a particular distance, locate the value (in pounds) pertaining to the particular carrying distance and percentile of the working population. For example, if a job requires carrying a tote box at elbow height for a distance of 14 feet, the maximum acceptable weight for 25 percent of the male workers is 50 pounds.

5.9.11.4. <u>Horizontal Push and Pull Forces</u>. The horizontal push and pull forces, to be applied initially to an object to set in motion or to be sustained for a period of time, shall not exceed the prescribed limits presented in Tables 4-6. These values were generated while pushing and pulling against a bar set at the indicated vertical heights on a treadmill surface. The posture used for pushing and pulling should be that posture most comfortable to the worker. The static horizontal push and pull forces exertable either intermittently or for short periods of time are presented on Table 7. For optimal pushing forces, the hands should be placed at a height between 38 and 44 inches from the floor on the object to be pushed, and the foot distance from the object's vertical plane should be between 53 and 61 inches. For optimal pulling forces, the bar height (i.e., the gripping surface) should be 37 to 43 inches from the floor, and the foot distance should be 8 to 9 inches from the vertical plane. The foregoing pertains to both males and females. In using Tables 4, 5, and 6 to estimate the recommended dynamic pushing and pulling forces for a particular vertical height from the floor, distance, and frequency, locate the mean value (in pounds) pertaining to those particular task variables. For example, if a job requires pushing a hand truck at a height of 57 inches above the floor once every minute for a distance of 7 feet, the maximum acceptable initial force for 25 percent of the male workers is 101 pounds.

5.9.11.5 <u>Handles and Grasp Areas</u>.

5.9.11.5.1 <u>General</u>. All removable or carried units designed to be removed and replaced shall be provided with handles or other suitable means for grasping, handling, and carrying (where appropriate, by gloved or mittened hand). The provision of handles generally allows for a 15% increase in lifting capacity.

TABLE 4
THE MAXIMUM ACCEPTABLE FORCES OF PUSH FOR MALES

Vertical Distance (in)*		100 ft. Push one push every					150 ft. Push one push every					200 ft. Push one push every				
		1	2	5 min.	30	8 hr.	1	2	5 min.	30	8 hr.	2	3	5 min.	30	8 hr.
INITIAL FORCE																
57"	x̄	51	55	64	68	73	48	51	60	64	68	46	46	53	57	62
	σ	12	15	15	17	17	14	14	15	19	19	14	12	15	17	17
37"	x̄	57	64	73	79	84	55	59	68	73	77	53	53	62	66	70
	σ	14	15	17	17	19	15	14	17	21	22	15	14	17	19	19
25"	x̄	46	55	62	68	70	44	51	57	62	66	44	46	53	57	59
	σ	10	14	15	15	17	12	12	17	19	21	12	12	14	15	17
SUSTAINED FORCE																
57"	x̄	29	35	40	42	46	26	33	37	40	44	26	29	31	35	37
	σ	7	9	10	12	12	7	9	9	10	10	7	7	9	9	10
37"	x̄	29	33	40	42	46	29	33	37	40	42	26	29	31	35	37
	σ	9	9	9	10	10	7	9	9	10	12	9	9	9	9	9
25"	x̄	29	33	37	42	44	29	31	35	37	42	29	29	31	33	35
	σ	9	9	9	9	10	7	9	9	10	10	7	9	7	9	10

Snook (1978)

*From floor to hands

TABLE 5
THE MAXIMUM ACCEPTABLE FORCES OF PUSH FOR FEMALES

INITIAL FORCE

Vertical Distance (in)*		100 ft. Push one push every					150 ft. Push one push every					200 ft. Push one push every				
		1	2	5 min.	30	8 hr.	1	2	5 min.	30	8 hr.	2	3	5 min.	30	8 hr.
53"	x̄	37	40	44	48	51	35	35	42	46	48	33	33	37	39	44
	s	7	10	9	9	10	5	7	7	7	9	5	5	7	9	7
35"	x̄	42	46	51	55	58	40	42	48	51	55	37	37	42	46	48
	s	9	10	10	10	10	7	7	7	10	9	7	7	9	9	9
22"	x̄	33	40	44	48	51	31	35	42	44	46	31	33	37	40	42
	s	7	9	9	9	9	7	7	9	9	9	5	5	5	7	9

SUSTAINED FORCE

Vertical Distance (in)*		100 ft. Push one push every					150 ft. Push one push every					200 ft. Push one push every				
		1	2	5 min.	30	8 hr.	1	2	5 min.	30	8 hr.	2	3	5 min.	30	8 hr.
53"	x̄	24	26	33	35	40	20	24	29	31	33	19	22	24	26	29
	s	3	5	5	7	7	5	5	5	5	5	3	5	5	5	5
35"	x̄	24	26	33	35	27	22	24	29	31	33	20	22	24	25	29
	s	5	5	5	7	7	3	5	5	5	5	5	5	3	5	5
22"	x̄	24	26	31	35	37	22	24	26	29	31	22	22	22	24	26
	s	5	3	5	3	7	3	3	5	5	7	3	3	5	5	5

Snook (1978)
*From floor to hands

97

TABLE 6

THE MAXIMUM ACCEPTABLE PULLING FORCES FOR MALES AND FEMALES

Vertical Distance (in)*		7 ft. pull (initial forces) one pull every							7 ft. pull (sustained forces) one pull every						
		6 sec.	12 sec.	1 min.	2 min.	5 min.	30 min.	8 hr.	6 sec.	12 sec.	1 min.	2 min.	5 min.	30 min.	8 hr.
Male 57"	x̄	42	43	55	57	64	66	68	26	35	42	42	46	48	51
	σ	12	14	14	14	15	15	17	7	10	12	14	15	15	15
Female 53"	x̄	42	42	42	44	48	51	53	31	31	33	33	37	37	40
	σ	10	12	10	9	10	12	12	9	9	9	9	9	10	10
Male 37"	x̄	59	68	77	79	88	92	97	33	44	55	57	62	64	66
	σ	15	17	17	19	21	21	22	9	14	17	15	19	21	21
Female 35"	x̄	57	59	59	62	68	70	75	40	42	42	44	48	51	51
	σ	15	15	12	12	15	15	15	12	10	12	12	12	12	15
Male 25"	x̄	68	77	86	90	99	103	108	35	48	59	59	66	68	70
	σ	17	19	21	21	24	24	26	10	14	17	19	19	21	22
Female 22"	x̄	64	66	66	68	77	79	84	40	44	44	51	51	53	55
	σ	17	17	15	15	17	19	19	12	12	12	12	14	14	14

Snook (1978)
*from floor to hands

TABLE 7

Least Horizontal Push Forces That Males Should be Able to Exert
Intermittently and for Short Periods of Time

Force	Applied With	Condition (μ: coefficient of static friction)
100N(25 lbs) Push or Pull	Both hands or one shoulder or the back	With low traction $.2 \leq \mu \leq .3$
200N(45 lbs) Push or Pull	Both hands or one shoulder or the back	With medium traction $\mu \sim .6$
250N(55 lbs) Push	One hand	If braced against a vertical wall (20-60 in) from and parallel to the push panel
300N(70 lbs) Push or Pull	Both hands or one shoulder or the back	With high traction $\mu \geq .9$
500N(110 lbs) Push or Pull	Both hands or one shoulder or the back	If braced against a vertical wall (20-70 in) from and parallel to the panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)
750N(165 lbs) Push	The back	If braced against a vertical wall (23-43 in) from and parallel to the push panel or if anchoring the feet on a perfectly non-slip ground (like a footrest)

Kroemer (1974)

5.9.11.5.2 Location. Handles or grasp areas shall be provided relative to the object's center of gravity (C.G.) in order to prevent swinging or tilting when lifted. Location of the handles should be at least 2.5 inches below the top edge of the container. Further, they shall be located to provide at least two inches (50mm) of clearance from obstructions during handling.

5.9.11.5.3 Nonfixed Handles. Nonfixed handles (e.g., hinged or fold unit) shall have a stop position such that the handle is perpendicular to the surface when held. Furthermore, the handles should be capable of being placed into carrying position by one hand where appropriate.

5.9.11.5.4 Grasp Surface. Where a unit's installation requires that its bottom surface be used as a handfold during removal or installation, a nonslip grasp surface, (e.g., grooved or frictional) shall be provided.

5.9.11.5.5 Handle Dimensions. Handles which are to be used with mittened, gloved, or ungloved hands shall approximately equal the following applicable dimensions: 1.5 inches for grip size, 5 inches in the sagittal plane; and 2.5 inches in the vertical plane.

REFERENCES

Åberg, U. Physiological and mechanical studies of material handling. Ergonomics Research Society Ann. Conf., p. 282, 1961.

Åberg, U., Elgstrand, K., Magnus, P. & Lindholm, A. Analysis of components and predictions of energy expenditure in manual tasks. The International Journal of Product Research, 6(3), 189-196, 1968.

Aghazadeh, F. Lifting capacity as a function of operator and task variables. Texas Tech University: Unpublished Thesis, August, 1974.

Alston, W.A., Carlson, K.E., Feldman, D.J., Grimm, Z. & Gerontinos, E. Quantitative study of muscle factors in the chronic low back syndrome. Journal of the American Geriatrics Society, 14(10), 1041-1047, 1966.

Anderson, G.B.J., Ortengren, R. & Nachemson, A. Quantitative studies of back loads in lifting. Paper to the International Symposium: Safety in Manual Materials Handling, Paper #54, Buffalo, New York, July 19-21, 1976.

Aquilano, N.J. A physiological evolution of time standards for strenuous work as set by stopwatch time study and two pre-determined motion time data systems. Journal of Industrial Engineering, 13(3), 425-432, 1968.

Asmussen, E., Poulsen, E. & Rasmussen, B. Quantitative evaluation of the activity of the back muscles in lifting. Communications from the Danish National Association for Infantile Paralysis, No. 21, 1965.

Ayoub, M.A. Optimum design for containers for manual material handling tasks. Paper presented at the International Symposium: Safety in Manual Material Handling, Buffalo, NY, 1976.

Ayoub, M.M. Lifting capacity of workers. Journal of Human Ergology, 6, 187-192, 1977.

Ayoub, M.M., Bethea, N.J., Deivanayagam, S., Asfour, S.S., Bakken, G.M., Liles, D., Mital, A. & Sherif, M. Determination and modeling of lifting capacity, Final Report, HEW Grant Nos. 1R010H00545-01 and SR010H-00545-02, September, 1978.

Ayoub, M.M., Dryden, R.D., McDaniel, J.W. & Knipfer, R.E. Psychophysical based models for the prediction of lifting capacity of the industrial worker. Society of Automotive Engineering, Automotive Engineering Congress and Exposition, Detroit, Michigan, paper #760023, Feb. 23-27, 1976.

Ayoub, M.M. & El-Bassoussi, M.M. Dynamic Biomechanical model for sagittal lifting activities. Paper presented at the International Symposium: Safety in Manual Materials Handling, State University of New York at Buffalo, July, 1976.

Ayoub, M.M. & Lo Presti, P. The determination of an optimum size cylindrical handle by use of electromyography. Ergonomics, 4(4), 503-518, 1971.

Ayoub, M.M. & McDaniel, J.W. Effect of operator stance on pushing and pulling tasks. AIIE Transactions, 6(3), 185-195, 1974.

Ayoub, M.M., McDaniel, J.W. & Dryden, R. Modeling in lifting activities. Paper presented at the American Industrial Hygiene Association Meeting, Boston, Mass., May 1973.

Ayoub, M.M. & Murthy, D.J.V. Optimum skeletal configuration under static pushing tasks. Unpublished Report, Department of Industrial Engineering, Texas Tech University, August, 1967.

Badger, D.W., Dukes-Dobos, F.N. & Chaffin, D.B. Prevention of low back injury in the industrial work force. A report on a NIOSH sponsored Symposium, November, 1972.

Bakken, Gary. Lifting capacity determination as a function of task variables and the development of prediction models based on the psychophysical approach. Unpublished report, Industrial Engineering Department, Texas Tech University, 1979.

Bastina, P.I., Gratsianskaya, L.N., Krasinskaya, G.F., Syromyatnikova, E.N. & Elkin, M.A. The effect of women's health by occupations involving frequent carrying of small weights. Public Health Engineering Abstracts, XLI (g), September 1961.

Block, C.T., Fine, G.T., Nemmer, W.C. & Wiersema, R.G. The effect of force moment on physiological cost while performing a lifting task. Unpublished report. Department of Industrial Engineering, Texas Tech University, 1966.

Bobbert, A.C. Optimal form and dimensions of hand grips on certain concrete building blocks. Ergonomics, 4(2), 141-147, 1960.

Brown, J.R. Lifting as an industrial hazard. Labour Safety Council of Ontario, Ontario, Canada, 1971.

Brown, J.R. The contributory factors to the development of low back pain in industry. Presented to the American Industrial Hygiene Conference, Miami, Florida, May, 1974.

Caldwell, L.S. Body position and the strength and endurance of manual pull. Human Factors, 6(5), 479-483, 1964.

Caldwell, L.S., Chaffin, D.B., Dukes-Dobos, F.N., Kroemer, K.H.E., Lauback, L.L., Snook, S.H., & Wasserman, D.E. A proposed standard procedure for static muscle strength. American Industrial Hygiene Association, 35(4), 201-206, 1974.

Chaffin, D.B. Some biomechanical considerations in manual materials handling tasks. Proceedings of the 15th Annual Meeting of the MTM Association, Ann Arbor, Michigan, 1967, as cited by Garg, 1976 (original not seen).

Chaffin, D.B. A computerized biomechanical model-development of and use in studying gross body actions. Journal of Biomechanics, 2, 429-441, 1969.

Chaffin, D.B. Human strength capability and low back pain. Journal of Occupational Medicine, 16(4), 248-254, 1974.

Chaffin, D.B. Biomechanical models of human strength in manual materials handling. Paper presented at International Symposium on Safety in Manual Materials Handling, Buffalo, New York, 1976.

Ciriello, J.M., and Snook, S.H. The effects of size, distance, height and frequency on manual materials handling performance. Proceedings of Human Factors Society, 22nd annual meeting, pp. 318-322, 1978.

Datta, S.R., Chatterjee, B.B., & Roy, B.M. The relationship between the energy expenditure and pulse rates with body weight and the load carried during load carrying on the level. Ergonomics, 16(4), 507-513, 1973.

Davies, B.T. Moving loads manually. Applied Ergonomics, 3(4), 190-194, December, 1972.

Davis, H.L., Faulkner, T.W. & Miller, C.I. Work physiology, Human Factors, 11(2), 157-166, 1969.

Davis, P.R. Posture of the trunk during the lifting of weights. British Medical Journal, 1, 87-89, 1959.

Drury, C.G. & Pfeil, R.E. A task-based model of manual lifting performance. Proceedings of the seventeenth annual meeting of the Human Factors Society, 457-464, 1973.

Emanuel, I., Chaffee, J.W. & Wing, J. A study of human weight lifting capabilities for loading ammunition into the f-86H aircraft. Wright Air Development Center Technical Report, AD 97206, August, 1956.

Ergonomics Guide to Manual Lifting. American Industrial Hygiene Association Journal, 31(4), 511-516, 1970.

Frederik, W.S. Human energy in manual lifting; modern materials handling; 14(3), 74-76, March, 1959.

Garg, A. A metabolic rate prediction model for manual materials handling jobs, unpublished Ph.D. dissertation, The University of Michigan, 1976.

Goldman, R.F. & Lampietro, P.F. Energy cost of load carriage. Journal of Applied Physiology, 17(4), 675-676, July 1962.

Haisman, M.F. & Goldman, R.F. Effect of terrain on the energy cost of walking with back loads and handcart loads. Journal of Applied Physiology, 36(5), 545-548, 1974.

Haisman, M.F., Winsmann, F.R. & Goldman, R.F. Energy cost of pushing loaded handcarts. Journal of Applied Physiology, 33(2), 131-183, 1972.

Hamilton, B.J. & Chase, R.B. A work physiology study of the relative effects of pace and weight in a carton handling task, AIIE Transactions, 1(2), 106-111, June, 1969.

Herrin, G.D., Chaffin, D.B. & Mach, R.S. Workshop Proceedings: criteria for research on the hazards of manual materials handling. Final Report, Contract CDC-99-74-118, NIOSH, 1974.

International Labour Office. Maximum permissible weight to be carried by one worker, Geneva, 1967.

Jones, D.F. Back strains: the state of the art. Journal of Safety Research, 3(1), 28-34, 1971.

Jones, D.F. Back injury research: a common thread. American Industrial Hygiene Association Journal, 33(9), 596-602, 1972.

Jorgensen, K. & Poulsen, E. Physiological problems in repetitive lifting with special reference to tolerance limits to maximum lifting frequency. Ergonomics, 17(1), 31-39, 1974.

Kamon, E. elding, H.S. The physiological cost of carrying loads in temperate and hot environment, Human Factors, 13(2), 153-161, 1971.

Karvenon, M.J. & Ronnholm, N. Electromyographic and energy expenditure studies of rhythmic and paced lifting work. Annales Academial Scientiarum Fennicae (Helsinki), 106(19), 101-115, 1964.

Kellerman, F.T. & Van Wely, P.A. The optimum size and shape of container for use by the flower bulb industry. Ergonomics, 4(3), 219-228, July 1961.

Konz, S.A. & Bhasin, R. Foot position during lifting. American Industrial Hygiene Journal, 35(12), 785-792, 1974.

Konz, S. & Desai, G. Lifting forces for nine lifting heights. III Symposium International de Posturographic Paris, September 23-26, 1975.

Konz, S, Sunil, D. & Corwin, B. Forces and torques in lifting. Human Factors, 15(3), 237-245, 1973.

Kroemer, E.K.M. Human strength: terminology, measurements, and interpretation of data. Human Factors, 12(3), 297-314, 1970.

Lind, A.R. & McNicol, G.W. Cardiovascular response to holding and carrying weights by hand and by shoulder harness. Journal of Applied Physiology, 25(3), 261-267, 1968.

Martin, J.B. & Chaffin, D.B. Biomechanical computerized simulation of human strength in sagittal-plane activities. AIIE Transactions, 4(1), 19-28, 1972.

McConville, J.T. & Hertzberg, H.T.E. A study of one-handed lifting. Antioch College, Yellow Springs, Ohio, and Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, May, 1966.

McFarland, R.S. Injury, a major environmental problem. Arch. Environ. Health, 19, 244-255, August, 1979.

Minard, D., Goldsmith, R., Farrier, P. & Lambiotte, B. Physiological evaluation of industrial heat stress. American Industrial Hygiene Association Journal, 32(1), 17-28, 1971.

Noro, L. Medical aspects of weight carrying. Industrial Medical Surgery, 36(3), 192-195, 1967.

Poulsen, E. Prediction of maximum loads in lifting from measurements of muscular strength. Communications from the Danish National Association for Infantile Paralysis, No. 31, 1970.

Ramsey, J.E. & Purswell, J.L. The correlation of mechanical and physiological measures of work movement of the upper limb. AIIE Transactions, 3(2), 97-103, 1971.

Ronnholm, H. Physiological studies in the optimum rhythm of lifting work. Ergonomics, 5(1), 51-52, 1962.

Ronnholm, H., Darvonen, M.J., & Lapinleimu, V.O. Mechanical efficiency of rhythmic and paced work of lifting. Journal of Applied Physiology, 17(5), 768-770, 1962.

Smith, L.E. ; Edwards, D.K. Prediction of muscular endurance (work performance) from individual differences in initial and post training increments in static strength. Human Factors, 10(4), 345-350, 1968.

Snook, S.H. The effects of age and physique on continuous work capacity. Human Factors, 13(5), 467-679, 1971.

Snook, S.H. The design of manual handling tasks. The Ergonomics Society lecture given at the Cranfield Institute of Technology, Bedfordshire, England, April 6, 1978.

Snook, S.H. ; Ciriello, J.M. Low back pain in industry. American Society of Safety Engineers Journal, 17(4), 17-23, April, 1972.

Snook, S.H. & Ciriello, V.M. Maximum weights and work loads acceptable to female workers. Journal of Occupational Medicine, 16(8) 527-534, 1974.

Snook, S.H. & Irvine, C.H. Maximum acceptable weight of lift. American Industrial Hygiene Association Journal, 28(4), 322-329, 1967.

Snook, S.H. & Irvine, C.H. Maximum frequency of lift acceptable to male industrial workers. American Industrial Hygiene Association Journal, 29(6), 531-536, 1968.

Snook, S.H. & Irvine, C.H. Psychophysical studies of physiological fatigue criteria. Human Factors, 11(3), 219-300, 1969.

Snook, S.H., Irvine, C.H. & Bass, S.F. Maximum weights and work loads acceptable to male industrial workers. American Industrial Hygiene Association Journal, 31(5), 579-586, 1970.

Soule, R.G. & Goldman, R.F. Energy cost of loads carried on the head, hands, or feet. Journal of Applied Physiology, 27(5), 689-690, 1969.

Stevens, S.S. Psychophysics: Introduction to its perceptual, neural, and social prospects. John Wiley & Sons, New York, 1975.

Streindberg, L. & Peterson, N.F. Measurement of force perception in pushing trolleys. Ergonomics, 15(4), 435-438, 1972.

Thomas, D.P. The effect of load carriage on normal standings in man. Journal of Anatomy, 93(1), 1959.

Tichauer, E.R. A pilot study of the biomechanics of lifting in simulated industrial work situations. Journal of Safety Research, 3(3), 98-115, 1971.

Tichauer, E.R., Milter, M.L. & Nathan, I.M. Lordosimetry: a new technique for the measurement of postural response to materials handling. American Industrial Association Journal, 1, 1-12, 1973.

Tichauer, E.R., Yagoda, H.P., Weinstein, J.M. & Well, R.A. Design criteria for packages and containers: a report on the state of the art, submitted to NIOSH, Cincinnati, Ohio, October 15, 1972.

Troup, J.D.C. Relation of lumbar spine disorders to heavy manual work and lifting. Lancet, 857-861, April 17, 1965.

Troup, J.D.C. & Chapman, A.E. The strength of the flexor and extensor muscles of the trunk. Journal of Biomechanics, 2, 49-62, 1969.

Van Wely, P.A. Manual lifting of loads. Ergonomics Research Annual Conference, 1961.

Whitney, R.J. The strength of the lifting action in man. Ergonomics, 1(2), 101-128, 1958.

Woodson, W.E. & Conover, D.W. Human Engineering Guide for Equipment Designers. Second edition, 2/246. University of California Press: Berkely, 1964.

APPENDIX

KEYWORDS: Maximal load, oxygen intake, pulse rate, mechanical work, electromyogram

METHODS: A series of investigations were carried out in an attempt to find out how large a maximal load can be safely allowed for each lifting action and how often this action can be performed, i.e., what is the maximal instantaneous effort and the long-time average of the mechanically produced work. The experiments were performed both as laboratory and field trials, but the laboratory trials have also had a rather strong practical connection. The following tasks were investigated:
1. Carrying weights in a rucksack while walking on a treadmill
2. Lifting beer cases
3. Baling operations in a pulp factory.
  Measurements were made primarily of oxygen intake, pulse rate and the mechanical work produced. Throughout the experiments, a description of the movements was made by means of suitable work study techniques. Electromyograms were taken in some of the tests.

RESULTS: The results supported the earlier findings by Atzler, Cathcart, and others, concerning the maximal load in relation to body weight. In the case of carrying on the back, energy consumption can be separated in two parts: one part caused by the vertical acceleration forces, and one part caused by the balancing of the load. This also seemed valid for other forms of work, e.g., work with a wheelbarrow. The pulp factory experiment showed a marked dependence on the relation between momentary work load and the distribution of pauses. Some of these results point to a serious drawback for older workers who are in the doubly un-pleasant situation of working near the upper limit of their ability and at the same time, because of insufficient strength, being compelled to use a method which is inferior from an energy-spending point of view.

SUMMARY: An attempt has been made to answer questions such as: how large of a maximal load can be safely allowed for each lifting action and how often can this action be performed?
  This study looks into an important area because carrying and lifting of loads still very frequently occurs even in highly mechanized industries.

CITATIONS: None cited.

STUDY: Aberg, U., Elgstrand, K., Magnus, P. & Lindholm, A. Analysis
            of components and predictions of energy expenditure in manual
            tasks. The International Journal of Product Research, 6(3),
            189-196, 1968.

KEYWORDS: Energy expenditure, model, work study

METHODS: A relationship between amount of work and human energy expendi-
            ture is given in an equation (sometimes called Johansson's rule).
            This states that for a specific situation, the energy expendi-
            ture can be expressed by the formula:

$$E = E_o + E_t + K \cdot A \ldots\text{where } E = \text{total energy expenditure}$$

            E_o = energy expenditure due to basal metabolism, E_t = energy
            expenditure due to the operation's movement empty handed,
            A = amount of external work performed, K = a proportionality
            constant.
               The present paper deals with an attempt to divide the terms
            E_t and $K \cdot A$ in simple elements which could be easily measured
            using ordinary work study methods.

RESULTS: A model for prediction of energy expenditure from physical data
            was proposed and was tested in a number of industrial cases.
            The accuracy of the result is in the same order of magnitude
            as a good work study.

SUMMARY: As the variables used for predicting the energy expenditure can
            be easily measured at the same time as the ordinary method and
            work study is done, a comparatively small extra effort might
            add another dimension to the design of job and work place.

CITATIONS: Seven references.

STUDY: Aghazadeh, F. Lifting capacity as a function of operator and
            task variables. Texas Tech University: Unpublished Thesis,
            August, 1974.

KEYWORDS: Low back pain (LBP), stepwise regression technique

METHODS: The report concerns itself with the causes and preventative
            measures of low back pain (LBP). It attempts to fully cover
            the scope of back injuries by examining the etiology of LBP,
            conducting experiments in order to determine lifting capacities,
            formulating and validating mathematical models incorporating
            operator and task variables, and investigating the effects of
            box size on lifting capacity. Previous studies which focus
            on the foregoing problems are also presented, along with a
            comparison between the previously generated data and the results
            of the present experiments. Further, a detailed description of
            the apparatus and techniques used in the present experiments
            are presented.

RESULTS: An analysis of those factors affecting low back pain indicated
            that age, sex, weight, height, and reduction of work space
            and dietary intake contribute to LBP. As far as the preventa-
            tive measures are concerned, pre-employment screening, training,
            and ergonomics were underscored. The ability to predict the
            effects of box size and other variables on the maximum permis-
            sible weight by the formulated mathematical models was found
            to be strong. However, it was shown that the predictive ability
            of a model was weakened with the addition of variables; the
            fewer the variables, the greater was the predictive ability of
            a model. Much of the data generated by the present experiments
            were used in determining the validity of the proposed models.
            In addition, it was found that the utilization of data from
            other relevant studies could serve as a valid procedure in the
            development of a model.

SUMMARY: In essence, the use of predictive models could provide a more
            effective means of matching the worker with the right job. This
            paper indicated that the optimum and simplest predictive model
            only needed to incorporate back strength and leg strength as
            variables. This model was found not only to have greater
            predictive ability, but required less equipment to use, saved
            money, and was more applicable.
                Although the effects of many operator and task variables
            were examined, further research needs to be conducted on such
            problem variables as temperature, noise, and humidity.. Further-
            more, the presented models only incorporated the floor to
            knuckle height and three box sizes. Consequently, future
            research should consider various lift ranges and box sizes
            when investigating the etiology of LBP.

CITATIONS: 72 references.

METHODS: Two groups of subjects were chosen. The first group included 32 male patients with low back symptoms and 32 male controls. These normal subjects were matched with the low back patients with respect to age, weight, and height scores from high to low, the scores being independent from each other. The second group included 20 subjects with low back syndrome, and 25 normal subjects matched with similar characteristics. The strength of the trunk flexors and trunk extensors and hamstring muscle tightness were obtained for the first group. These were obtained by measuring the force developed by a maximal isometric contraction. Three determinations were made for flexors and extensors and the average result was considered representative. Then strength of the abdominal and psoas muscles were determined for the second group.

RESULTS: 1. There was a significant difference in the strength in the trunk flexion between normal subjects and those with low back syndrome.
2. A similar difference existed in the strength in trunk extension.
3. No significant difference was noted between the trunk flexion-extension ratios for the controls and the ratios for the patients.
4. The psoas muscle strength was clearly diminished in the patients with low back pain as compared to the controls, but the relationship to total trunk flexion strength and abdominal strength was statistically the same for both normal subjects and those with low back pain.
5. Tightness of the hamstring muscle groups of one or both lower extremities is common in patients complaining of low back pain of this type. The incidence was significantly increased in the patients as compared to the controls.

SUMMARY: In 32 male patients with the chronic low back syndrome and 32 normal male controls, measurements were made of the strength of the trunk flexors and extensors and of hamstring muscle tightness. In another group of 20 similar patients and 25 controls, the strength of the abdominal and psoas muscles was determined. The results led to the following conclusions: Chronic low back pain not associated with demonstrable bone or disc disease is frequently accompanied by generalized weakness of the trunk muscles, but there is a normal relationship between flexor and extensor muscle groups as indicated by the F/E ratio. No selective weakness of

Alston, et al., 1966 (continued)

SUMMARY: (continued)
             flexors or extensors of sufficient degree to disturb this ratio
             was found in this study.
                Tightness of hamstring muscle groups of one or both lower
             extremities is common in patients complaining of low back
             pain of this type. The incidence was significantly increased
             in the patients as compared to the controls. The use of back
             supports and therapeutic exercise as means of eliminating these
             muscle factors is of great help.

CITATIONS: Five references.

113

STUDY: Anderson, G.B.J., Ortengren, R. & Nachemson, A. Quantitative studies of back loads in lifting. Paper to the International Symposium: Safety in Manual Materials Handling, Paper #54, Buffalo, New York, July 19-21, 1976.

KEYWORDS: Intervertebral disc pressure, intra-abdominal pressure

METHODS: The intervertebral disc pressure in the third lumbar disc, the intra-abdominal pressure and the myoelectric activity of several muscles of the back have been recorded simultaneously. Four healthy subjects were studied. Lifting was performed with the back straight and knees flexed (leg-lifting) as well as with the back bent and the knees straight (back-lifting). Studies were also made when a load was held at various distances from the body. Static experiments were also studied. They comprised pulling a handle placed 40, 50, or 60 cm above the floor with the back either straight or flexed.

RESULTS: The intervertebral disc pressure was about the same in back-lifting and leg lifting; back-lifting yielded a slight but systematically higher pressure. The distance from the body at which the weight was held was more important than the technique of lifting. In all investigations there were only minor changes in the intra-abdominal pressure. It was not possible to reduce the disc pressure by voluntarily increasing the intra-abdominal pressure. The time-course of the myoelectric activity was about the same in back-lifting as in leg-lifting. The disc pressure values and the intra-abdominal pressure values were about the same when pulling was performed with the back straight and flexed. The myoelectric signal amplitudes were significantly higher when pulling was performed with the knees flexed and the back straight and the handle placed at 40 or 50 cm above the floor. When the handle was at 60 cm, the amplitudes were about the same regardless of the posture of the back.

SUMMARY: Instructions in manual handling are used with increasing frequency to reduce the load on the back during manual work. There are comparatively few investigations, however, in which the load on the back has been measured when different methods of lifting are adopted. Further, the results differ in different investigations. The purpose of the present work is to analyze differences in load on the back when lifting is performed using different techniques.

CITATIONS: None cited.

STUDY: Aquilano, N.J. A physiological evaluation of time standards
             for strenuous work as set by stopwatch time study and two pre-
             determined motion time data systems. Journal of Industrial
             Engineering, 19(9), 425-432, 1968.

KEYWORDS: Time standard, predetermined motion time data, work physiology,
             elemental data,work sampling

METHODS: An experiment was designed to investigate whether workers, while
             performing moderate to strenuous tasks at time standards set
             by traditional industrial engineering methods, experience
             physical demands which are considered 'reasonable' from a
             physiological point of view and whether the time standards
             developed for different tasks are consistent in requiring the
             same levels of energy expenditure. In the experiment, experi-
             enced workers performed carton handling tasks while heart rate
             and oxygen consumption were monitored. To conduct the experi-
             ment, time standards based on conventional engineering methods
             were first developed. The energy costs for performance at
             these time standards were then obtained and compared to levels
             suggested by physiological studies. Standard times were obtained
             by the analysts by multiplying the normal times by an allowance
             factor which included personal and fatigue time. The physio-
             logical level used for comparison in this study was 4Kcal above
             the sitting rest level. Another assumption was that 4Kcal above
             the seated rest level corresponds to incentive performance.
               Carton handling was selected as the type of work to be per-
             formed. A sample of six subjects was selected from a population
             of about 500. Each subject performed two trials of each of
             the six tasks at three paces, for a total of 36 runs per sub-
             ject. The faster pace was set at 128 percent of the standard
             rate which had been developed previously. The heart rate and
             the oxygen consumption were monitored both during and previous
             to the work period.
               Regression analysis was performed with work pace as the in-
             depent variable and Kcal as the dependent variable.

RESULTS: Using 4Kcal as the physiological level corresponding to 128
             percent performance, a comparison was made of the energy
             expenditure rates. At the incentive pace determined by the
             standard analysts, wide differences from this level resulted.
             Performance by individual subjects varied from 32 percent below
             to 189 percent above this level. At standard pace also, energy
             demands were high.
               Since such large differences were observed in performing the
             tasks, a simple test was made to determine the extent to which
             conventional methods were compatible with physiological recom-
             mendations. Five of the six subjects performed task 1 and
             task 3 using empty cartons. This was done to get an estimate
             of low weight energy expenditure. The figures for energy
             expenditure showed that energy requirements for body motion
             alone are in the range of the 4Kcal level.

Aquilano, 1968 (continued)

RESULTS: (continued)
             It was concluded that the standard times developed for this
         study were valid for unladen body movement and are consistent
         with physiological recommendations. However, as weight is
         added, a rapid increase occurs in energy requirements.

SUMMARY: An experiment was designed to investigate whether workers,
         performing moderate to strenuous tasks at time standards set
         by traditional testing methods, experience physical demands
         which are considered 'reasonable' from a physiological point
         of view or not, and whether the time standards developed for
         different tasks are consistent in requiring the same levels
         of energy expenditure or not.
             The time standards developed for this study were unacceptable
         from a physiological point of view. Great differences in
         energy demands from reasonable levels and a large variance
         among tasks were observed. The major discrepancy was thought
         to be in the rest allowances. The study entailed the per-
         formance of six carton-handling tasks by experienced workers.
         At incentive pace, energy expenditure levels ranged from 32
         percent below the assumed 4Kcal level to 189 percent above it.
         At standard time they ranged from 46 percent below to 125
         percent above the 4Kcal level.
             The study stresses the need for setting standards by methods
         which take the physiological factors into account. In the
         moderate to strenuous work situation, time standards based on
         conventional methods do not seem to work. It can be used to
         determine and estimate time standards for manual materials
         handling jobs, applying the work physiology techniques.

CITATIONS: Twelve references.

METHODS: The measurements of the force produced during isometric con-
               tractions of the back muscles were performed by means of a
               strain guage-dynamometer. The force is measured during an
               attempted extension of the back in the erect position with a
               strap around the shoulders across the deltoid muscles. Weights
               to be lifted were placed in a box with two handles, about 40 cm
               apart, and weighing 2.5 kg. The subjects were instructed to
               keep their backs straight although not overextended, and at an
               angle to the vertical of 45°. Hips and knees were flexed and
               the feet placed about 50 cm apart. Control experiments showed
               that the degree of flexion in the knees and the placement of
               the feet had no influence on the muscle activities of the back
               under the experimental conditions. The EMG was recorded by
               means of paired silver electrodes. After measuring the strength
               of the back muscles, the subject was released from the dynamo-
               meter and the lifting operations were started. The subject
               grasped the two handles of the box containing the weights and
               assumed the standard position: feet apart, knees bent, back
               straight and inclined 45° forward. He maintained this position
               for a few seconds while EMG and IEMG were recorded.

RESULTS: There is a correlation between the weight that is carried in the
               hands in a forward inclined position and the force that the
               muscles of the back must develop.   This force, probably be-
               cause of the supporting action of the intra-abdominal pressure.,
               is less than what should be expected. It would be safe to esti-
               mate that people with otherwise normal backs are able to hold
               loads (inclusive weight of head, arms, and part of the trunk)
               weighing up to 140 percent (100/cos 45°) of their maximum iso-
               metric back strength, measured at the height of the shoulders,
               provided the spine is held in a normal position and the trunk
               is not inclined more than about 45° forward in the hips. For
               long lasting holding in this position, the figures must be re-
               duced. For frequently repeated lifts, it must correspondingly
               be reduced with a factor .8 to .6, depending on the frequency.
               In practical daily jobs, a further reduction to half of these
               maximal values must be recommended in order to eliminate the
               weight of head, arms and trunk and to obviate chronic fatigue.
                 The rule must then be: about 70 percent of maximum isometric
               back strength for single, short lasting lifts; 55 to 40 percent
               of isometric strength for lifts repeated 10 to 30 times per
               minute; and 30 to 35 percent for continued holding of about 1
               minute duration.

SUMMARY: As a hypothesis it is assumed that lifting of loads from the
               ground should be carried out with the spine as nearly as

                                   117

Asmussen, et al., 1965 (continued)

SUMMARY: (continued)
possible in the habitually curved position. In this position
the muscles of the back rather than the ligaments counteract
the pull of gravity. In a series of experiments, the pulls
exerted by the back muscles when holding loads in a 45° forward
tilted position are estimated from the integrated EMG of the
muscles and the established relationship between integrated
EMG and isometric backward pulls. It was found that the esti-
mated forces were less than the theoretically predicted forces,
especially at higher loads. Possible reasons for this differ-
ence are discussed. Practical hints for estimating allowable
maximal loads from measurements of isometric back strength are
given.

CITATIONS: Ten references.

STUDY: Ayoub, M.A. Optimum design for containers for manual
material handling tasks. Paper presented at the Inter-
national Symposium: Safety in Manual Material Handling,
Buffalo, N.Y., 1976.

KEYWORDS: Torque, bulk, optimization model, Lagrange multiplier,
simplex method

METHODS: Several examples which outline and detail the problems
associated with the design of containers were presented.
For example, given a container having a particular con-
stant weight, what would its dimensions have to be in
order to preclude excessive torque on the lower lumbar
region? Or, given a container with fixed dimensions, what
would its weight have to be if the torque at the L5/S1
were to be kept constant?

RESULTS: The foregoing examples attempted to emphasize that the de-
sign of containers is basically a problem of mechanics.
Several models centering on the biomechanical approach
were presented as viable approaches for dealing with spe-
cific container design problems.

SUMMARY: The elimination of problems arising as a result of hazard-
ous practices in container design is important. However,
it should not preclude analysis of other industry-related
factors (i.e., consideration of man, task, environment). In
light of this, the modeling approach in biomechanics stands
to contribute the most, for it offers flexibility in the
analysis of problem variables in an integrated and complete
fashion.

CITATIONS: Seven references.

119

STUDY: Ayoub, M.M. Lifting Capacity of workers. Journal of Human Ergology, 6, 187-192, 1977.

KEYWORDS: Physiological, psychophysical, biomechanical approaches, task variables

METHODS: Lifting capacity, in this paper, was defined as the amount of load lifted repeatedly at the rate of one lift/minute in a compact box. With this definition in mind, a comparison of the lifting capacity as determined by the psychophysical and physiological methods for different studies was made.

RESULTS: 1. Lifting Capacity
It is defined as the amount of load lifted repeatedly at the rate of 1 lift/minute in a compact box. The physiological and psychophysical methods are compared; also, one lifting height is used (from floor to the height of 29 inches above floor, or floor to knuckle height). The lifting capacities using several techniques are given in tabular form.
2. Effect of Frequency
Several investigations indicated that lifting capacity decreased when the frequency of lift increased. Assuming a linear effect of frequency, there was no agreement between either the physiological or the psychophysical approaches.
3. Box Size Effects
All psychophysical studies pointed out that as the size of the load increased in the sagittal plane, the mean weight lifted decreased. No data on the box size effects using physiological approaches was available.
  The study showed that there were some disagreements in the data obtained between investigators using the same approach and between the different approaches used. These disagreements in the lifting capacity and the task variables were the result of several factors:
1. Differences in methodologies used.
2. Differences in the subject population and its characteristics.
3. The wide variation in the lifting tasks used by the several investigators and the demands of these tasks in terms of strength and endurance.
  In summary, the author suggested that it is essential to resolve some of these differences by simultaneously using several methodologies in a single study under well-controlled conditions.

SUMMARY: This paper provided a comparison of the lifting capacity as determined by the following methods:
1. Physiological method
2. Psychophysical method
Also, how this capacity was modified when three basic task variables were considered. These task variables were:
1. Lifting height
2. Lifting frequency
3. Box size lifted

120

Ayoub, 1977 (continued)

<u>CITATIONS:</u>   Thirteen references.

KEYWORDS: Lifting capacity, psychophysical approach, task variables, job stress index

METHODS: This study was designed to determine the lifting capacity of the male and female industrial population for six different height ranges, four levels of frequency (2, 4, 6, and 8 lifts per min), and three different box sizes (12 in., 18 in., 24 in., in the sagittal plane).

A balanced incomplete block factorial design was used. There were 73 male and female subjects. The dependent variable was the maximum acceptable weight of lift, which was arrived at using the psychophysical approach.

Lifting capacity prediction models were developed. Also, field data were collected to determine the effects of job demands on back injuries and the relationship of job stress index (job demand/individual capacity) and potential injury.

RESULTS: The lifting capacity for males and females differed significantly. There was a linear effect of box size and frequency on the lifting capacity. Sex code was the most important factor in predicting the lifting capacity of males and females. Age had no effect on the lifting capacity, either for males or females.

SUMMARY: Lifting capacity norms and prediction models were developed. These data and models are needed for job design and employee placement/selection.

CITATIONS: One hundred thirty-seven references.

STUDY: Ayoub, M.M., Dryden, R.R., McDaniel, J.W. & Knipfer, R.E. Psychophysical based models for the prediction of lifting capacity of the industrial worker. Paper presented at Automotive Engineering Congress & Exposition, Detroit, paper #760080, February 23-27, 1976.

KEYWORDS: Maximum acceptable lift, psychophysical model, lift ranges

METHODS: Subjects were required to lift tote boxes from the floor to standing knuckle height, knuckle to shoulder height through a range of 50.8 cm, and shoulder to reach height through a range of 50.8 cm. Following the lift to the proper height the box was placed on a table which lowered the box to its starting height. As well as the lifting performance, anthropometric strength, and physiological measurements and parameters were recorded. The measures were taken so as to allow the subjects time to recover between performance measures from fatigue. The comparison of the working heart rate with the resting heart rate was used to determine the number and duration of the rest periods. The procedures followed a psychophysical approach in that the subjects adjusted the weight of the box, but did not know the weight of the box. The instructions given the subject were to adjust the weight to a level which could be lifted repetitively during an 8 hour day. The subjects lifted 4, 6, 8 times respectively for the floor to knuckle, knuckle to shoulder, and shoulder to reach heights. Subjects lifted for a maximum of 45 minutes. Subjects were recruited from industry.

RESULTS: Predictive models of the weight of maximum acceptable lift were developed. A stepwise regression procedure was used to formulate these models. The predictive capability of the models for the upper range of lifting were lower than the models for the lower ranges of lift. Males were found to have higher levels of maximum acceptable lift than females. For 90% levels of males the maximum weight is 155.75 newtons, for the same range of the female population the maximum weight is 84.55 newtons.

SUMMARY: Research was conducted to formulate predictive models of maximum weight of acceptable lift. Using a psychophysical approach models for three ranges of lift were developed. Maximum acceptable weight was lower for women than for men ranging from 49% to 62% of the maximum acceptable weight for men. The predictive models were viewed as having potential as screening methodologies in selecting proper job placement of workers in jobs requiring lifting activities.

CITATIONS: Ten references.

123

METHODS: Leg lifting and back lifting were compared using different
             weight loads and different box sizes. The model was used to
             determine the strain on the musculoskeletal system during these
             two types of lift. Body segment parameter data, external weight
             carried, initial and final configurations of the body links and
             total movement time for each link with its relation to the other
             links were found and put into the dynamic biomechanical model.
             The model then produced the angular displacement, velocity, and
             acceleration for each segment which could be used to calculate
             tangential and normal accelerations. Next, using the accelera-
             tions, the reactive forces and torques could be calculated.
             The forces and torques allow the shear forces on the spine
             during the lifting action to be determined.

RESULTS: The lifting comparisons were made in terms of hip torque, com-
             pressive and shear forces on the spine at L-4/L-5 and L-5/S-1,
             and the postures during the lifting action where maximum com-
             pressive and shear forces occur. The model simulated both
             methods of lifting showing each articulation path. The data
             showed that maximum compressive forces are higher for back
             lift as compared to leg lift. As the stress increases for
             the lifting task, the rate of change in stress on L-5 increases
             at a higher rate for the back lift method. In either method
             of lift, the most stressful posture occurs right after the
             lifting action has started. The model also shows how the com-
             pressive and shear forces change as the operators posture
             changes while lifting. The model also simulates the lifting
             showing the operator's posture as a function of time. The
             results also show the linear changes in the stresses with
             increase of the difficulty of the task as the box length is
             increased.

SUMMARY: The dynamic biomechanical model was used to determine the
             strain on the musculoskeletal system during the lifting action
             using leg and back lifts. Compressive and shear forces were
             found and during the action of lifting, these forces increase
             rapidly, reach a peak early and gradually decrease in value
             towards the end of the lift.

CITATIONS: Thirty-three references.

STUDY: Ayoub, M. M. & Lo Presti, P. The determination of an optimum
              size cylindrical handle by use of electromyography. Ergonomics,
              4(4), 503–518, 1971.

KEYWORDS: Electromyography, hand size, weight resistance, hand cylinder

METHODS: The task, to determine an optimal size cylindrical handle, con-
              sisted of reaching to the handle, the lower edge of which was
              located 18 in. above the work surface. Each subject was re-
              quired to grip the handle using his preferred hand in a power
              grip and then to pull the handle straight down toward the tar-
              get marked on the flat horizontal surface of a simulated work
              piece located 12 in. directly below the original static position
              of the handle. Upon making contact, instructions were to hold
              for 3 seconds, then return the handle to the original position
              and release it. This was repeated 5 times. The position of
              the subject was such that a sagittal plane would pass through
              the center of the suspended handle and his shoulder joint.
                  In addition, another task, procedurally identical, but in-
              volving the element of fatigue, was performed by each subject.
              In this investigation "optimum size hand cylinders" meant that
              diameter of cylindrical handle which resulted in: the maximum
              ratio between the grip force and the EMG activity of the flexor
              and extensor muscle groups; the longest work period before the
              onset of fatigue, the criterion being the working time until
              the onset of synchronization of action potential on the EMG
              trace.
                  A pulley system was designed such that the handle was sus-
              pended from one side and counter-balanced by various weights.
              The tension in the line is referred as the weight resistance.
              A special dynamometer was designed and built for reading the
              force exerted by the hand. This was cylindrical with the pro-
              vision of changing the diameter by stages up to a maximum of
              3 in.
                  A completely randomized block design was used with subjects
              serving as blocks.

RESULTS: Handle sizes were highly significant. A handle 2.5 in. in dia-
              meter resulted in the least msucle activity in performance of
              the experimental tasks, and the 1.5 and 2 in. handles showed
              slightly higher electromyographic activity.
                  Weight effect was also highly significant. More muscle
              activity was required to produce large force.
                  It was possible to exert the greatest grip force on the 1.5
              in. diameter handle and the least on the 2.5 in. diameter
              handle. If the ratio of the grip force to the EMG activity is
              considered, the best efficiency is obtained for the 1.5 in.
              diameter handle.

Ayoub & Lo Presti, 1971 (continued)

RESULTS: (continued)
             Results of the fatigue experiments were similar to the main
             experiment. A 2.5 in. diameter handle was less desirable as
             compared to 1.5 in. and 2 in. diameter handles, but was pre-
             ferred to a 1.25 in. diameter handle.
             The handle of best size proved to be that of 1.5 in. in
             diameter.

SUMMARY: An experiment was designed using muscle electromyography to
             determine if an optimum cylindrical handle size exists. First
             phase of the experiment was concerned with an experimental task
             of gripping a cylindrical handle and performing a simple task
             routine to evaluate the optimum size. The second phase was
             concerned with a fatigue test, using the same handles. Hand
             size, weight resistance and cylindrical handle diameter were
             the experimental variables.
             Results indicated that the 2.0 in. diameter handle showed
             least EMG activity, but the 15. in. diameter handle was found
             to be the optimum handle size based on the ratio between force
             applied and the EMG activity measured. Also, the 1.5 in. dia-
             meter handle was found to provide the maximum number of comp-
             pleted task cycles before the onset of fatigue.
             This research has application in the design of couplings for
             industrial containers. Optimal handle size can accompany a
             container with optimal weight/bulk ratio.

CITATIONS: Fourteen references.

126

STUDY: Ayoub, M.M. & McDaniel, J.W.   Effect of operator stance on
         pushing and pulling tasks.   AIIE Transactions, 6(3), 185-195,
         1974.

KEYWORDS: Pushing and pulling capacities, task configurations, stress on
            the spine, bar height, shoulder height, foot distance, reach
            height.

METHODS: The subjects were instructed to push against the handle of the
           apparatus keeping the arms extended at the elbow and the rear
           leg extended at the knee.   They were further instructed to posi-
           tion their left foot approximately 12 in. in front of the right
           foot while applying their maximum push for 5 sec.   In the case
           of pulling, the rear foot was maintained off the floor.
              The height of the subject was removed as a variable by choos-
           ing the bar height (BH) and foot distance (FD) as percentage of
           the shoulder height or reach height.   Reach height (RH) in this
           study was defined as the distance from the floor to the grip
           center in overhead reach.   Shoulder height (SH) was measured
           from the floor to the acromion.   The foot position distance
           from the handle was defined as the distance from the vertical
           plane of the handle to the lateral malleolus.   The elbow angle
           was removed as a variable.

RESULTS: It can be concluded that the best position for pushing tasks
           can be found when the force is applied to the load at a height
           of approximately 70 percent shoulder height or 50 percent reach
           height and the rear foot should be located at a distance of
           approximately 100 percent SH or 70 percent RH.
              For pulling, the hands should apply the forces at a distance
           of 40 percent of shoulder height above the floor, while the
           front foot should be at a distance of 10 percent of shoulder
           height from the plane of force application.   Several other
           findings are also important.
           1.   Maximum fatigue is found when foot distance is between 70
                percent and 80 percent shoulder height or approximately 50
                to 55 percent reach height.
           2.   The optimum bar height should be as low as possible to yield
                the longest time.
           3.   The female subjects, although unable to achieve pushing
                forces as high as the males, have been able to maintain the
                maximum forces for longer periods than the males.

SUMMARY: The main objectives of this study were to: 1) investigate the
           capabilities of man in pushing and pulling tasks as they are
           affected by the different body configurations, 2) determine if
           optimum configurations would exist for both the pushing and
           pulling tasks, and 3) evaluate the stress on the spine during
           such activities as pushing and pulling tasks.

CITATIONS: Twelve references.

127

METHODS: Each subject was instructed to lift a weight from the floor and place it on the lifting machine shelf adjusted to his knuckle height. Each subject was also instructed to adjust the amount of weight in the box so that he was lifting as much weight as he could lift in this manner for a period of a normal working day. Based on the findings of Brown (1970), the subject lifted this box in the manner most comfortable to him.

RESULTS: I. Model 1 (2 final models were selected)

1. Model for males - based on 10 cases:
Predicted maximum lift=-172.356 + .022 $(height)^2$ -2.73 $(static\ end.)^2$ + .021 x (RPI x arm st.) + .053 (RPI x back st.) - 2.513 (fitness/dynamic end.); Multiple R=.9331; Prediction Error=8.78 percent

2. Model for females based on 15 cases
Predicted maximum lift= -24.027 +.194 $(RPI)^2$ + .006 (arm st. x leg st.); Mutiple R=.7443; Prediction Error=6.83 percent

II. Model 2
The following two relationships are used

$$X_t = \frac{X_T}{2\pi} \left[\frac{2\pi t}{T} - Sin\ \frac{2\pi t}{T} \right] \qquad (i)$$

$$\theta_t = \frac{\theta_T}{T} \left[\frac{2\pi t}{T} - Sin\ \frac{2\pi t}{T} \right] \qquad (ii)$$

where

X_t = displacement of time t

X_T = maximum displacement, the distance between initial and terminal points measured in that distance

θ_t = angular displacement of time t

θ_T = maximum angular displacement

SUMMARY: A need exists for generalized models capable of predicting lifting capacities of man and lifting stresses imposed on him while lifting loads. Two types of models are thus discussed here:

1. Performance Models
2. Biomechanical Models

The performance models attempt to develop correlations between physical characteristics and lifting capacities of industrial workers. These models would predict lifting capacities for

128

Ayoub, et al., 1973 (continued)

SUMMARY: (continued)
             several lifting heights with reasonable degree of accuracy.
             The biomechanical models attempt first to apply Newtonian
             mechanics to the human frame to provide data on reactive
             forces and torques on the various joints, links and other
             critical parts of the human frame. Once these biomechanical
             models are developed, they can also be used for predictive
             purposes. Predictive models for performance, as well as
             biomechanical models are very useful in gaining insight into
             the factors and methods in lifting activities that relate to
             lifting capacity of man. Both types of models attempt to
             determine lifting capacity of man, given certain physical
             characteristics and constraints.

CITATIONS: Nine references.

METHODS: In order to select different skeletal configurations the follow-
          ing two methods were considered:
          1. The subject's skeletal configurations were defined by two
              angles
              a. the angle between the subject's extended arm and the
                  horizontal plane through shoulders. Range: $-30°$ to
                  $40°$, $10°$ intervals.
              b. the angle between the rear lower extremity and the
                  floor surface. Range: $60°$ to $80°$, $10°$ intervals.
          2. The skeletal configuration of the subject was determined
              by two variables:
              a. Distance A: the height of the crossbar above the floor
                  surface
              b. Distance B: defines the location of the ankle joint as
                  measured from the vertical plane passing through the
                  crossbar.
          Distance A: 6 levels, 60, 70, 80, 90, 100 and 110 percent of the
          shoulder height.
          Distance B: 6 levels, 50, 60, 70, 80, 90, and 100 percent of
          the shoulder height.
             Each subject was placed in front of the experimental equip-
          ment, and, according to a randomized order, a measurement was
          taken for the horizontal and vertical forces during leaning as
          well as maximal pushing for each of these configurations. Dur-
          ing both leaning and maximal pushing, the subjects maintained:
          1. a fully extended arm
          2. full knee extension of the rear lower extremity, and
          3. the front foot was not in contact with the floor.

RESULTS: The results reported in this paper are those for method 2 only.
          1. Effects of Measurement A (cross-bar height)
              As the cross-bar is raised, the leaning horizontal and push-
              ing forces increase. The resultant leaning as well as the
              resultant pushing force increase as the cross-bar is increased
              in height. The effects of A on leaning vertical and push-
              ing vertical forces were nonsignificant.
          2. Effects of Measurement B (horizontal distance of rear foot
              from cross-bar)
              While the leaning horizontal and leaning resultant forces
              increase almost linearly with the increase in B, the push-
              ing horizontal forces increase nonlinearly and level off
              after B has reached 90 percent of the shoulder height. It
              appears that the maximum forces due to muscular contraction

130

Ayoub & Murthy, 1967 (continued)

RESULTS: (continued)
            appear when the rear foot is at 80 percent of shoulder height
            away from the vertical plane through the cross-bar. The
            effect of B on the leaning and pushing vertical forces were
            not significant.

SUMMARY: This paper describes the preliminary work in progress whose
            purpose is to determine the skeletal configuration that will
            result in the maximum pushing forces and compare these with
            those providing the maximum force due to muscular contractions;
            in addition, it will answer some questions concerning the com-
            ponent that the body weight contributes toward the total
            pushing force. The ultimate goal is to construct a biomechani-
            cal model of pushing and pulling tasks. The program consists
            of two phases:
            1. The Static Phase: Biomechanical analysis of tasks while
                the subject is pushing or pulling against a stationary
                load.
            2. The Dynamic Phase: Biomechanical analysis of tasks while
                the subject is pushing or pulling against a load and both
                the subject and the load is in motion.

CITATIONS: Seven references.

STUDY: Bastina, P.I., Gratsianskaya, L.N., Krasinskaya, G.F.,
            Syromyatnikova, E.N. & Elkin, M.A. The effect of women's
            health by occupations involving frequent carrying of small
            weights. Public Health Engineering Abstracts, XLI(g),
            September 1961.

SUMMARY: The maximal weight of a single load lifted at a time by a woman
            is set at 20 kg, but the law fails to specify the sum of weight
            lifted during the whole of a shift. In order to obtain hygienic
            backgrounds for rating this total weight lifted in the course
            of one day by women, the authors have examined at two brick
            works 146 women workers permanently engaged in transporting
            relatively small loads during the whole of the work day. These
            women-workers revealed a series of physiological shifts, repro-
            duction disturbances, and a high percentage of occupational
            diseases of the skeletal and motor systems.
               The authors suggest that the total weight shifted per work
            day by women should be subject to a standard rating, and
            recommend measures to improve working conditions prevailing at
            brick works.

CITATIONS: None cited.

METHODS: The experiment used a four factor design.   Three test positions
              were administered to each of three subjects in a pre-determined
              random order sequence.   The second replication was taken in the
              same manner.   A total of six tests were recorded in each posi-
              tion.   Three female subjects each performed the same lifting
              tasks while pulmonary ventilation, heart rate, and electrical
              potential of the sacrospinalis muscle were measured.   All tasks
              performed by the subjects consisted of lifting a 20 lb. weight
              a total of 7 inches.   The time interval from the initiation to
              the termination of the lift was 0.05 minute and the rest cycle
              was a constant 0.10 minute.   The distance from the fifth lumbar
              vertebrae to the center of the test weights was the only inde-
              pendent variable introduced in this project.   Electrocardiogram
              and electromyogram readings were made at rest and continuously
              during the test, and exhaled air volume was recorded at the end
              of each minute of work.

                 The exhaled air volume was used as a qualitative measure of
              O_2 consumption.   The difference between pulmonary ventillation at
              rest and at work is the amount of ventilation which is required
              by the work.   The electrocardiogram was used for pulse rate
              determination.   Changes in configuration and amplitude of the
              myogram are an indication of muscle fatigue and are read direct-
              ly from the recorder chart.

RESULTS: The main effect of positioning the test weight from the lumbar
              spine showed that the larger moment arms resulted in a higher
              average ventilation rate due to work.   This shows that more O_2
              was used and thus more energy was required to perform the work
              at the larger moment arms.   Even though all the subjects showed
              this same upward trend in ventilation rate, there were great
              differences in the individual rates.   This can be attributed
              to the differences in body chemistry of individuals and to the
              fact that the individual operators use different groups of
              muscles in the lifting task.

                 In regard to time, the ventilation rate increased as the work
              period progressed.   This can be attributed to the fact that the
              muscles are not getting enough O_2 from the red corpuscles of the
              blood and therefore must start using the O_2 stored in the muscle
              fiber.   The pulse rate is related to the ventilation rate in
              that as the muscles go into "O_2 debt" the pulse rate will in-
              crease in order to supply O_2 to the blood at a faster rate.

Block, et al., 1966 (continued)

SUMMARY: The established purpose of this project was to demonstrate the physiological cost of various moments of force about the fifth lumbar vertebrae. In addition, this project demonstrated an objective method of measuring energy consumption and fatigue. Pulmonary ventilation, heart beat and electrical potential of the sacrospinalis muscle were selected as measures of physiological cost.

It was observed that a person can fatigue his muscles to the point of strain, or transfer the load onto the lumbar vertebrae causing an injured or slipped disk, without being aware that they have achieved this overloaded condition. Proper training of personnel can allow the muscle load to be shared between the deltoid and sacrospinalis muscles thereby decreasing the proportionate stress each receives.

CITATIONS: Five references.

STUDY: Bobbert, A. C. Optimal form and dimensions of hand grips on certain concrete building blocks. Ergonomics, 4(2), 141-147, 1960.

KEYWORDS: Dimensions, hand-grips, concrete building blocks

METHODS: A series of 29 sets of hand-grips were moulded of clay or wood, They were variations of the 21 hand positions resulting from technical restrictions and functional-anthropometric considerations.

In order to carry out experiments with the different sets of hand-grips, the grips were mounted upon an iron bar and loaded with a weight in such a way that both the distance between the hand-grips and the weight of the original concrete blocks were simulated. Two subjects were studied performing a standard task with this model. The task consisted of lifting and replacing the model over a fixed height and according to a prescribed time schedule. Pulse rate and oxygen consumption during work were measured. Four hand-grips were studied. It was concluded that the work of handling concrete blocks could be increased by fitting them with finger-grips. But as there was no definite correlation between oxygen consumption and pulse rate on one hand and the depth of the finger-grip on the other, maximal lifting power was taken as a criterion on the assumption that high maximal lifting power correlates with good quality of grip.

Each of the 29 sets of hand-grips was then fitted with a spring ergograph. Six subjects, wearing plastic gloves, were asked to pull with each set of grips four times in succession with their maximal force. The mean of the 24 values obtained with each set was called the 'maximal lifting power.'

RESULTS: When comparison was made of the results obtained by measurements of oxygen consumption and pulse rates and by determination of maximal lifting power, it was clear that the latter criterion is superior. The superiority of the maximal lifting power as a criterion also appears from the fact that the lifting power discriminates between 2mm changes in the depth of finger-grips.

The highest values of maximal lifting power (85.7kg) was found with an ideal grip (No. 29). The grip dimensions are (in mm): a=0, b=65, c=40, x=10, y=36, z=13 curved length=80 where

        a=distance from thumb-grips to upper face of block,
        b=width of upper face,
        c=distance between finger-grip and upper face,
        x=depth of thumb grip,
        y=thickness of concrete partition between tips of thumb
          and fingers, and
        z=depth of finger-grip.

For technical reasons grip number 24 was selected. The maximal lifting power of this differed only slightly from the ideal of

135

Bobbert, 1960 (continued)

RESULTS: (continued)
            number 29. The various dimensions are: a=0, b=65, c=40, x=10,
            y=42, z=13, straight length=80, maximum lifting power=81.7kg.

SUMMARY: The optimal form and dimensions of hand grips for handling cer-
            tain types of concrete building blocks were found by theoretical
            considerations and laboratory experiments. Such grips were
            found to reduce the physiological work load considerably. The
            maximal lifting power proved to be a better criterion for the
            evaluation of minor changes in dimensions of hand grips than
            energy expenditure of heart rate during work.
              This study has application in modern building practice, where
            the shape of the concrete block can be changed to reduce the
            physiological work load. The maximum lifting power can also be
            applied to determine hand-grips in lifting objects similar to
            concrete blocks.

CITATIONS: Four references.

METHODS: To uncover some of the causes of lower back pain, a questionnaire
was designed which covered aspects such as physical fitness, job
satisfaction, postural fatigue, recreational activities and medical
care. Of 1000 employees, 509 returned the completed or partially
completed questionnaire. The employees were of varied occupation
and covered areas like warehouse, hospital, removal and storage,
and light industry. Anthropometric data for the subjects was also
collected and dated to check if there was a significant difference
between the subjects with back injury and general population.

RESULTS: A number of interesting observations were made from the returned
questionnaires. There was an excess of 11 percent of back injuries
in females (46 percent) over males (35 percent). Those with
injuries lasting more than 6 months constituted 5.8 percent of the
women and 5.3 percent of the men. Twenty-five percent of the men
and 7 percent of the women with back injuries received workmen's
compensation. Ten percent of men and women with back injuries
received compensation for more than 6 months. Fifty-eight percent
of the men and 30 percent of the women took sick leave for back
trouble. Only 49 percent of the replies gave the opinion that
lifting was the cause of their low back pain. The accident rate,
for injuries other than back injury, was 2-1/3 times that of
women for men. It was revealed that 21 percent of the men and
30 percent of the women did not engage in athletic games. Forty-
eight percent of the total population did not attend lectures
or demonstrations on lifting and 37 percent of those with back
injuries did not attend. However, it was found that 77 percent
of the sample adopted the lifting methods advocated in educational
programs. Eighty-two percent of individuals with back injuries
used the prescribed method. It is interesting to note that 92
percent of the population returned to their original job following
treatment. There was no evidence that people with back injuries
changed jobs more frequently than those without. Fifty-two
percent of the sample with back injuries did not wear non-skid
shoes. Fifty-one percent of the men thought that loads up to
50 lbs. were not unreasonable, but 36 percent of the women thought
the load should not exceed 30 lbs. Only 20 percent of the men
and 7 percent of the women lifted 50 lbs.

SUMMARY: The results of the questionnaire indicate the variety of factors
which may be responsible for development of low back pain in
industrial workers. Questionnaires were sent to 1000 workers
in a variety of industrial occupations including hospital work.
A sample of 509 replies was obtained and a number of observations
were made on the incidence, duration and treatment of low back

137

Brown, 1974 (continued)

SUMMARY: (continued)
           pain in industry. An opinion considering the role of accident
           prevention program and non-skid footwear was obtained.
             Most of the individuals did not lift weights greater than
           they thought to be reasonable.
             The questionnaire study was of an exploratory nature and
           serves as a useful pilot study. It is helpful in the develop-
           ment of further questionnaires and indicates the areas from
           which useful objective results may be obtained.

CITATIONS: Two references.

STUDY: Caldwell, L.S. Body position and the strength and endurance of manual pull. Human Factors, 6(5), 479-483, 1964.

KEYWORDS: Elbow, thigh, knee-angles, maximum pull force to measure strength, maximum time of holding response in seconds to measure the endurance

METHODS: Prior to actual testing the subjects were given practice in pulling maximally on the handle and in maintaining a goal force as long as possible. The strength and endurance trials were presented as a pair in each practice session. Five such sessions spaced at least 4 hours apart were presented. In each session the subjects were first told to pull as hard as possible without "slamming" the handle and to keep trying to increase the force until the experimenter terminated the trial in 8 seconds. A 3 minute rest period was given and then the subject was required to hold a force proportionate to his own strength as long as possible. In these endurance trials the display amplifier was set so that the green light would turn on at a force equal to 90 percent of the maximum force measured in the immediately preceding strength trial. In the endurance trials the subject was simply instructed to keep the green light on as long as possible. The endurance trial was terminated when the subject ceased responding, or when he was unable to turn the green light on again within 3 seconds.

RESULTS: I. Strength
The effect of thigh and knee positions on the strength of manual pull reflects the importance of body stabilization in the production of control forces. The knee-angle influences the force exertable by the legs against the backrest by varying the output of the toggle formed by the legs between the foot rest and back rest. As the thigh-angle increases the force developed by the legs tends increasingly to wedge the subject into his seat and trunk stabilization is improved. As the elbow-angle increased, there was a progressive increase in strength ($p < .01$). Thus an increase in strength was obtained as body stabilization was improved by either increasing the elevation of the thigh or by straightening the leg, and an improvement in strength was reached as the arm was straightened.
  Significant F-ratios were:
  thigh-angle ($p < .01$)
  knee-angle ($p < .01$)
  elbow-angle ($p < .01$)
  thigh-angle x subjects ($p < .01$)
  knee angle x subjects
  thigh-angle x knee-angle ($p < .01$)

II. Endurance
Essentially the same results were obtained as in strength data.
  Significant F-ratios were:
  thigh-angle ($p < .01$)

139

Caldwell, 1964 (continued)

RESULTS: (continued)
    knee-angle (p < .05)
    elbow-angle (p < .01)
    thigh-angle x knee-angle (p < .01)

SUMMARY: The purpose of this study was to test the assumption that the
control position or body attitude in which an operator can
develop the greatest momentary control force - or at which
response strength is greatest - is also the position in which
a given sub-maximal force can be maintained for the longest
time.   Since a substantial correlation was obtained between
strength and endurance of a sub-maximal response, the "goodness"
of various control and body positions for extended performance
can be estimated in many cases from existent strength data.

CITATIONS: No references.

METHODS: 1. Static strength is measured according to the following conditions:
    a. Static strength is assessed during a steady exertion sustained for 4 seconds.
    b. The transient periods of about 1 second each, before and after the steady exertion are disregarded.
    c. The strength datum is the mean score recorded during the first 3 seconds of the steady exertion.
2. a. The subject should be informed about the test purpose and procedure.
    b. Instructions to the subject should be kept factual and not include emotional appeals.
    c. The subject should be instructed to increase the maximum exertion (without jerk) in about 1 second and maintain this effort during a 4 second count.
    d. Inform the subject during the test session about his general performance in qualitative, non-comparative, positive terms. Do not give instantaneous feedback during the exertion.
    e. Rewards, goal setting, competition, spectators, jeers, noise, etc. can affect the subject's motivation and performance and, therefore, should be avoided.
3. The minimum rest period between related efforts should be 2 minutes.
4. Describe the condition existing during strength testing:
    a. Body parts and muscles chiefly used.
    b. Body position.
    c. Body support/reaction force available.
    d. Coupling of the subject to the measuring device (to describe location of the strength vector).
    e. Strength measuring and recording device.
5. Subject description:
    a. Population and sample selection.
    b. Current health status medical examination/questionnaire is recommended.
    c. Sex.
    d. Age.
    e. Anthropometry (at least height and weight).
    f. Training related to strength testing.
6. Data reporting:
    a. Mean (median, mode).
    b. Standard deviation.
    c. Skewness.
    d. Minimum and maximum values.
    e. Sample size.

141

Caldwell, et al., 1974 (continued)

METHODS: (continued)
            In an experimental study the maximum voluntary strength of
            handgrip was measured along the instruction conditions employed
            by Kroemer and Howard. A pair of trials separated by a rest
            of two minutes was given for each instruction condition. No
            information feedback was provided.

RESULTS: The data were analyzed to determine:
            1. The effects of instructions on the time required for each
                maximum force application.
            2. The relationship between instruction conditions and the
                obtained strength measures.
            3. The relationship between strength and method of force
                generation.
            With instructions to apply force as rapidly as possible,
            38 percent of the subjects reached their maximum output within
            the first second, 41 percent took between one and two seconds,
            12 percent required from two to three seconds, and 9 percent
            took more than three seconds.
            The instruction to increase gradually to maximum output and
            then release led to extremely variable performance. Twelve
            percent attained maximum force within one second; 15 percent
            took from one to two seconds; 21 percent reached maximum
            between two and three seconds; 21 percent took from three to
            four seconds; 6 percent needed from four to five seconds; and
            27 percent took more than five seconds.
            For "hold" only three percent of the subjects reached maximum
            output in the first second; 24 percent required between one to
            two seconds; 29 percent took two to three seconds; 26 percent
            took three to four seconds; 9 percent required four to five
            seconds; and the remaining 9 percent reached maximum after five
            seconds.
            For all instruction conditions the times-to-maximum data
            were skewed toward the longer times. For "Jerk", "Increase",
            and "Hold", the values were 1.54, 1.84, and 1.67 respectively.
            In 31 of the 34 cases maximum force was attained fastest with
            the "jerk" instruction. In 19 cases the longest times were
            obtained in the "increase" condition, and in 14 instances longest
            times were found with "hold" instruction. Differences between
            instruction conditions were significant. The mean time-to-
            maximum strength for the "jerk", "increase", and "hold" condi-
            tions were 1.4, 4.1, and 2.8 seconds respectively.
            There was little difference in the measures obtained with the
            various instructions. All instruction conditions yielded
            reliable measures of strength, and differences in reliability
            did not provide a basis for recommending one procedure over
            the others.
            The results emphasize the necessity for explicit instructions
            to subjects in strength assessment studies.

142

Caldwell, et al., 1974 (continued)

SUMMARY: An attempt was made to standardize the procedure for static
            muscle strength testing. Different sets of instructions
            were given to subjects to determine their effects on the time
            required to reach maximum force application, the relationship
            between instruction conditions and the obtained strength
            measures, and the relationship between strength and method of
            force generation.
               It was concluded that the results were so similar for the
            three methods that differences in reliability did not provide
            a basis for recommending one procedure over the other, and
            the necessity for explicit instructions to subjects was
            emphasized.

CITATIONS: Twenty references.

METHODS: Chaffin (1969) developed a computerized biomechanical model
             which can be used to estimate the forces and torques that are
             created at six major articulations of the body (i.e. wrist,
             elbow, shoulder, hip, knee, and ankle) as well as at the fourth
             lumbar through the first sacral spinal vertebrae of a person
             performing weight-handling tasks.   The model has been referred
             to as the static sagittal plane model (SSP) and evaluated
             various "static" situations such as when one is holding weight,
             or pushing or pulling on a nonmoving container.   The model can
             also be used to analyze "slow" moves by formulating the input
             data to describe a sequence of static positions with very small
             changes in each successive position.   However, a rotation or
             lateral deviation can not be analyzed.   The model treats the
             body as a series of seven solid links which are articulated at
             the ankles, knees, hips, shoulders, elbows, and wrists.   The
             body measurements needed as input data are: body stature,
             body weight, center-of-gravity of the hand to wrist distance,
             lower arm length, lower leg length, foot length, and elbow
             height when standing.   From these, the link lengths are esti-
             mated.   The task under analysis is described by two types of
             data.   First, external force that may be exerted against the
             hands is measured and entered into the program as a vector
             acting at the c.g. of the hands.   The second type of informa-
             tion required to describe the activity is the position of the
             body.   To obtain these data, it is necessary to measure the
             articulation angles from either a lateral photograph of a
             person, or from an articulated drawing board body template
             placed in the "Task" position.
               The above data are sufficient for the model to compute the
             torques and forces at each of the six major articulations of
             the body.
               To perform the analysis of the lumbar spinal stress, the
             following concepts were included in the SSP model:
             1. The geometry of an average erect spinal column, proportion-
                 ally scaled in the model based on the hip-to-shoulder dis-
                 tance.
             2. The curvature change for the column during sagittal rota-
                 tion of the hips.
             3. The contribution of intra-abdominal pressure in relieving
                 compression on the lumbar spine.
             4. The amount of pressure created by the abdominal pressure
                 was estimated by assuming the following:
                 a. a diaphragm area of 465 sq. cm. and a pelvic area of
                     517 sq. cm. upon which the abdominal pressure can act.

Chaffin, 1969 (continued)

METHODS: (continued)
           b. the line of action of the force acts parallel to the
              line-of-action of the normal compressing forces on
              the lower lumbar spine.
           c. the force acts through finite moment arm distances from
              the center of the disks.
     5. Additional compressive forces on the lumbar spine due to
        the abdominal muscles were assumed to be negligible.
     6. The line of action of the muscles of the lower lumbar back
        were assumed to act parallel to the normal compressing force
        on the vertebral/disk interface, and with a moment arm of
        5.0 cm.
A "muscle strength" evaluation was included in the model.
  To test the model, a group of 13 volunteers (10 males, 3 fe-
males) were employed in the following tests:
1. Procure anthropometric data
2. Test each subject's voluntary strength for the seven
    isolated muscle group actions.
3. Have each subject perform a maximum lift with legs and
    back while holding handles attached to load cells secured
    to the floor, and at the point of maximum effort take a
    lateral photograph to enable the measuring of the body
    position.
  The above data were used in the SSP model, which computed
estimates of both the major articulation torque and the com-
pressing and shearing forces at the L4/L5 and L5/S1 disk verte-
bral body end plates during the lifting tasks.

RESULTS: When the articulation torques produced during the lifting task
were compared to the maximum voluntary torques determined by
the isolated muscle group strength tests, it was found that the
predicted strength limits were not exceeded or equaled during
the lifting task. The knee extension torque during the task
came the closest, as it ranged from 73 to 95 percent of the
tested maximum voluntary knee extension torque. The hip exten-
sion torque during the lifting task was found to range from 18
to 75 percent of the subject's maximum voluntary hip extension
torque as determined by the prior strength tests. It was con-
cluded from these results that for this particular lifting
task the subjects were not limiting their performances due to
the muscle group strengths that were tested.
  An analysis of the compressing and shearing forces at the
lower lumbar spine during the lifting task, as predicted by the
model, disclosed that the subjects appeared to limit their
compressive forces to a fairly constant magnitude, regardless
of their potential hip and knee extension strengths. Similar
results were found for the disk/L5 inferior surface, disk/L5
superior surface, and disk/L4 inferior surface.

Chaffin, 1969 (continued)

SUMMARY: A computer model is developed which treats the human body as a
series of seven links, from which reactive forces and torques
are computed at each articulation during various simulated
materials-handling tasks. In addition, an analysis of shear-
ing and compressing forces at the lower lumbar spine is in-
cluded.
   The use of SSP model has disclosed that, in at least one type
of lifting circumstance, the strengths of a group of major
muscles do not appear to dictate the whole-body lifting capa-
city. It is proposed that either the limited muscle strength
of the back extensors, or the sensing of possible injury to
the vertebral column due to excessive compressing forces, in-
hibits the lifting action.
   Further development of the SSP model can be used in analyzing
different types of lifting conditions that are encountered
in heavy industry and are often the course of injury to the
musculo-skeletal system.

CITATIONS: Thirty-seven references.

METHODS: The study involved 103 different jobs populated by 411 men and women. Visits to the medical departments were recorded over about a one year period, thus making a total exposure of 17,430 man-weeks, during which time 25 low-back incidences occurred in the study group. The procedure included a job evaluation of the 103 jobs included in the study. This evaluation was done by using an index, the lifting strength rating (LSR), which was simply the largest value of the following:

$$LSR = \frac{\text{Each weight lifted}}{\text{Predicted lifted strengths for large/strong man}}$$

This predicted strength was determined from a previous study (Chaffin, D.B. & Baker, W.H. A biomechanical model for analysis of symmetric sagittal plane lifting. AIIE Transactions, 2(16) 1970) and a number of high strength requiring jobs (LSR>0.5) as well as a number of lower strength requiring jobs. Then a strength test was performed with the person in two different lifting postures. First, they were placed in a position wherein their hands were 20 inches in front of the ankle of the leading foot, and 20 inches above the floor. This was referred to as the Standardized Position Strength Test. The second test position required the person's hands to be placed in the location dictating the LSR rating on the job. This was referred to as the Job Position Strength Test. They were asked to slowly apply a lifting force to the handles (which were 18 inches apart). When they reached what they believed to be the level of force they could tolerate on any present or future job, they were asked to hold that load for three seconds. The testing device was designed to average the demonstrated force over a three second period. The computation of the low-back pain incidence rate for each job was simply accomplished by dividing the number of separate incidents for the people on each job by the man-weeks of exposure of the people to the job during the study period.

RESULTS: The first result of interest was simply the distribution of strength among the people participating in the study, which was skewed, with the women having a 58 percent mean strength of the men and a 65 percent of the men's modal value. A ratio of the weight lifted on the job to the mean strengths of the employees on that job (from Job Position Strength test) was formed. And this ratio was referred to as "Strength Ratio". The results indicated a sharp increase in the mean low-back pain incidence rates (by a factor of 3:1) for those jobs populated by persons who did not demonstrate sufficient strength to equal or exceed that required to lift the weight that generates the highest predicted stress on the job.

147

Chaffin, 1974 (continued)

SUMMARY: The objective of the study was to determine if an isometric strength test of a person's ability to lift weights would correlate with the incidence rate of low-back pain. A strength test was developed and was used to estimate the individual's strength on both a standardized position and on the posture required by the job. Results show that women had a mean strength of 58 percent that of men and 65 percent of the men's modal value. Also the results indicated a sharp increase in the mean low-back pain incidence rates for those jobs populated by persons who did not demonstrate sufficient strength equal to or exceeding that required by the job.

CITATIONS: Twenty-six references.

METHODS: Biomechanical strength models are based on a kinematic linkage representation of the human body. To manipulate the body posture, a set of angles are the inputs of the model. Biomechanical strength modeling involved the comparison of maximum voluntary torque (VT) and the torques (RT, called "resultant torques") resulting from the forces acting at the hand, body segment weights, and any external constraints. Maximum voluntary torques representing the strength of the subject and, therefore, required as input to the model are calculated from data gathered on carefully controlled and dimensional test equipment. A person's voluntary strength (often referred to as "reactive torques") depends upon a number of factors. The major factors are: 1) body position, 2) individual characteristics such as health, prior training, sex, age, etc., 3) motivation, and 4) level of fatigue at the time of exertion. Muscles react to an externally applied force by "pulling" across articulations. The ability of a muscle to produce a torque varies with the included angles of joints across which it is pulling.

RESULTS: By using a polynomial regression analysis of 18 (10 males and 8 females) subject's elbow flexion strength at different positions, the group's average value can be expressed as follows:

$$VT = 336.29 + 2.088*\alpha - .015*\alpha^2 - 3.364*\beta + .019*\beta^2 \quad \text{(Eq. 1)}$$

where:

VT = Mean max. voluntary elbow flexion reactive torque (inches-pounds).

α = Elbow included angles (degrees).

β = Shoulder vertical abduction angle (degrees).

To account for individual characteristics, the VT predicted above is multiplied by a factor called the "subject strength coefficient" designated C_i and by "left-right adjustment" designated C. An individual's elbow flexion strength is then represented by:

$$VT_i = C_i*C(336.29 + 2.088*\alpha - .015\alpha^2 - 3.364*\beta + .019\beta^2)$$

where

C_i = Subject strength coefficient.

C = a parameter to account for the difference in right and left elbow strength.

On an average $C_1 = 1.00$ for right elbow, $C_1 = .93$ for left elbow for a right-handed person.

C_i = The ratio of the max. measured strength (reactive torque) of a given muscle group for a selected body position (body angle) of ith subject to the predicted mean strength (Eq. 1) of the same muscle group for the same body position over all subjects considered in population.

SUMMARY: This paper gives a procedure which established the various muscle groups strengths for different body postures. These strengths or voluntary torques are then systematically compared to the

149

Chaffin, 1976 (continued)

METHODS: (continued)
            resultant torques at the joints due to gravity acting on both
            an object being handled and on the body masses. In doing
            this, if a specific posture has not been used as an input, the
            model will iterate through various angles at the joints,
            keeping the hands and feet in the same relative position.
            With each iteration of a posture, all the joint voluntary
            torques are checked to determine the maximum load that can be
            applied to the hands to cause a resultant torque to equal one
            of them. This hand load is thus the maximum predicted
            strength of the body in that posture.

CITATIONS: Twenty-one references.

STUDY: Ciriello, J.M., and Snook, S.H. The effects of size, distance, height and frequency on manual materials handling performance. Proceedings of the Human Factors Society, 22nd annual meeting, pp. 318-322, 1978.

KEYWORDS: Manual materials handling, psycophysical, heart rate, oxygen consumption, frequency, males

METHODS: Fifteen second-shift, male industrial workers from local industries performed 61 variations of lifting, pushing and pulling. To establish the maximum acceptable weight, a psychophysical methodology was employed whereby the test subject controlled the amount of weight or force being handled. The vertical distances of lift were 25, 51, and 76 cm. These distances of lift were studied at three heights: 1. floor level to knuckle height, 2. knee height to elbow height, and 3. knuckle height to shoulder height. Two box lengths (the distance between the hands) of 57 cm and 89 cm were investigated. For each box length, there were three corresponding box widths (the distance away from the body) of 36, 49, and 75 cm. A depth of approximately 14.4 cm was used for all boxes. The boxes had handles located midway on the width dimension. Lifts were performed once every 9, 14, and 60 seconds and once every 8 hours. Dynamic pushing and pulling tasks were simulated on a specially constructed treadmill. Pushing and pulling were performed at three heights: 1. shoulder height (147 cm), 2. a distance midway between knuckle and elbow height (97 cm) and 3. 15 cm below knuckle height (65 cm). Five pushing lengths were studied: 2.1 m, 7.6 m, 30.5 m, 45.7 m, and 61.0 m. Pushing frequencies ranged from once every 15 seconds to once every 8 hours, depending on the length of the push or pull.

RESULTS: The results of this experiment indicated that box size (specifically the width), distance, height and frequency are significant variables to consider when establishing guidelines for maximum acceptable weights.

SUMMARY: Fifteen second-shift, male industrial workers from local industries performed 61 variations of lifting, pushing and pulling tasks to investigate the effects of task frequency, height, distance, and box size. A psychophysical methodology was employed whereby the test subject controlled the amount of weight or force being handled. Measurements of heart rate, oxygen consumption, and body size were also taken. The results indicated that box size, distance, height and frequency are significant variables to consider when establishing guidelines for maximum acceptable weights.

CITATIONS: Ten references.

METHODS: Six healthy volunteers were chosen for the experiment. These
           subjects had an average age of 29.4 years (range 23-40), an
           average height of 163.3 cm (range 162.0-171.1 cm) and body
           surface area (B.S.A.) 1.62 m^2 (range 1.49-1.66 m^2). They were
           asked to carry loads (0, 20, 30, 40, and 50 kg) on their heads
           in a basket for a period of 12 min. so as to cover a measured
           distance of 1 km (5 km/hr).

           Energy expenditure was determined by collecting the expired
           gas in a Douglas bag during the final two minute period of walk-
           ing. The Douglas Bag and accessories were supported by an
           attendant walking immediately behind the subject at the same
           speed. The volume of the collected expired gas was measured
           by passing it into a large calibrated spirometer and the minute
           ventilation was computed. The oxygen consumption was determined
           with a Haldone gas analysis apparatus. The heart rate was
           measured by timing 20 beats with a stop watch with the subject
           standing still with whatever load he had been carrying imme-
           diately after completion of his walk.

RESULTS: The observed energy expenditure in kcal/min (E) for walking with
           no load and while carrying 20, 30, 40, and 50 kg loads on the
           head were plotted: 1) separately against the weights of the
           loads (L) carried as well as the gross weights, i.e., the total
           of the subject's body weight (W) and the weight of the load
           itself (L) and 2) the values of peak heart rate (PHR) were also
           plotted against L and (W+L). The regression equation obtained
           between energy expenditure (kcal/min) and gross weight (W+L in
           kg) transported was:
           $E = 0.0943(W+L)-2.1833$
           and that between the PHR and the gross weight transported was:
           $PHR = 1.2552(W+L)+24.87$.

           The coefficient of correlation between the energy expenditure
           and gross weight transported was $r=0.91$ and between the peak
           heart rate and gross weight transported was $r=0.88$. The corre-
           lation between the load carried and the peak heart rate ($r=0.79$)
           are also between the load carried and energy expenditure
           ($r=0.89$) were numerically less than the ones described above.

           The finding with regard to the relationship of total weight
           and energy expenditure to the load carried was similar to
           earlier findings that the energy cost per unit weight is essen-
           tially the same regardless of the distribution of total weight
           between body weight and load.

           The regression equations for energy expenditure (E) and peak
           heart rate to the gross weight transported show that it is
           possible to predict the values of these physiological parameters,

152

Datta, et al., 1973 (continued)

RESULTS: (continued)
            while carrying loads on the level, with a high degree of accuracy
            for individuals of similar body type as the subjects chosen for
            this study.
                The applicability of these regressions was verified by an
            independent series of experiments. There was good agreement
            between the predicted and observed values. It was noted that
            the observed values of energy expenditure and peak heart rates
            tended to be greater than the predicted values for subjects
            with lesser body weights than the group studied earlier and
            were less than the predicted ones if the subject's body weight
            was greater than the body weights of the group studied earlier.

SUMMARY: In a study of load carriage on the head on the level, high
            degrees of correlation were obtained with the gross weights
            transported (viz. body weight and given load) and the energy
            expenditures, r=0.91. Their relationship fits the equation,
            E(kcal/min)=0.0943 (body weight + load carried) - 2.183. The
            gross weight transported was also found to have an equally
            high correlation with the peak heart rates observed (r=0.88)
            and the regression equation, PHR=1.2552 (body weight + load
            carried) + 24.87, mathematically describes the relationship of
            the two latter variables.
                These equations can conveniently be used for field studies of
            load carrying in many underdeveloped countries where the common
            mode of load carriage is identical with that investigated in
            this study and the average weight of the subjects around 50kg.

CITATIONS: Seven references.

STUDY: Davies, B.T. Moving loads manually. Applied Ergonomics 3(4),
               190-194, December, 1972.

KEYWORDS: Initial force, sustained force, lift range

METHODS: Considering the number of industrial accidents attributed to the
               lifting and handling of materials, it is vital that an attempt
               be made to construct an objective criterion to facilitate match-
               ing the worker with the right job. This paper addresses various
               industry-related questions, with the intention of giving employers
               a better idea of the capabilities of industrial workers.

RESULTS: In essence, the report posed the following questions: how much
               can we expect a worker to lift and carry?; how often can we
               expect a woman operator to lift a given weight?; and how can we
               reduce the number of back injuries in industry? These questions
               were partially answered via the provision of past regulations
               which dictated manual materials handling practices. For example,
               in 1958 the Pottery (Health and Welfare) special regulations
               propounded that a woman or young person must not carry more than
               18.1 kg (40 lb) more than 45.7 meters (50 yd) on a level sur-
               face. Other regulations prescribed a "heavy" weight as being
               35 percent of the worker's body weight. The report also ad-
               dressed such problems as how dress affects work efficiency, team
               work coordination in lifting, the use of yokes and harnesses in
               carrying loads, and the relationship between the pace of moving
               loads and energy expenditure.

SUMMARY: Considering the variety of prescribed norms governing the hand-
               ling of manual materials, determination of any single relevant
               criterion is difficult. However, some reasonable answers, taking
               into account the multitude of factors which can affect them,
               may be: 1. a healthy, experienced male should not be expected
               to lift more than 55 kg (120 lb); 2. a woman's strength is
               generally about 65% of the strength of adult men; and 3. all
               workers expected to lift light and heavy loads should be taught
               the proper techniques of lifting and moving loads.

CITATIONS: Twenty references .

STUDY: Davis, H.L., Faulkner, T.W. & Miller, C.I. Work physiology, Human Factors, 11(2), 157-166, 1969.

KEYWORDS: Work physiology, lifting, rest periods, heart rate, O_2 consumption

METHODS: The authors used heart rate and O_2 consumption to estimate the load placed upon operators performing physically difficult tasks. The energy expenditure was calculated from the O_2 consumption. The people participating in this study were studied under controlled conditions available in the laboratory and then were studied as they performed their normal job. A criterion of 5 cal/min. was considered as an average maximum work load for a healthy young male and this load was not expected to produce an average heart rate exceeding 120 beats/ min. About 33 jobs were evaluated using energy consumption and heart rate as the criteria for the severity of the jobs.

RESULTS: It was concluded that it is practically impossible to estimate accurately the difficulty of a job by merely observing it. The number of different factors that have a bearing on task difficulty is very large. One of the studies evaluated the effect of the length of the rest periods on a lifting task (lifting a 40 lb. case from floor level to a table 20 inches above floor at the rate of 6 lifts/min). The results showed that the heart rate continued to rise during the working period when a rest period of 2 minutes was given every 10 minutes, while such an increase did not take place when the rest period was 7 minutes for every 10 minute work period.

SUMMARY: The paper shows that one of the most useful techniques of analysis of different jobs is work physiology, as it is practically impossible to estimate accurately the difficulty of a job by merely observing it.

CITATIONS: Eight references.

STUDY: Davis, P.R. Posture of the trunk during the lifting of weights.
                British Medical Journal, 1, 87-98, 1959.

KEYWORDS: Posture, lifting, abdominal pressure

METHOD: Three questions are proposed by the author. These questions
                are: (1) How are heavy weights lifted? (2) What part does
                the trunk play in this? (3) What damage may be produced?
                The answers to these questions stem from personal observation
                of a large number of people engaged in their everyday tasks.
                Davis then explains these answers through the usage of relevant
                anatomy.

RESULTS: This paper gives an idea about the different ways of lifting
                weights. It emphasizes the part played by the trunk in lifting
                and that the trunk should be straight always, especially in
                case of heavy loads. The author then classifies the injury of
                the trunk into two basic types. The anterior, extrusive group
                of injuries, which includes visceral herniae and prolapses; and
                the spinal group, including such lesions as the lumbo-sacral
                strain; prolapsed intervertebral disks at the lumbar and cervical
                levels, and tears of posterior ligaments and spinal muscles.
                The mechanisms resisting the different forces in lifting are
                basically two. The first is the spinal column and its muscles,
                and the second is the "pneumatic" mechanism created by the ab-
                dominal pressure in the abdominal cavity. The author also
                emphasizes the danger of flexing the spine as it creates high
                abdominal pressures.

SUMMARY: Davis (through personal observations by workers) examines ways
                of lifting weights and the part played by the trunk. A review
                of the literature made it apparent that lesions caused by
                weight-lifting rarely appear in the limbs, but are not uncommon
                in the trunk. In giving an anatomical explanation of the obser-
                vations, Davis divided the analysis into two stages. Firstly,
                by examining the forces exerted on the trunk when weight-lifting
                in different positions; and secondly, by examining the mechanisms
                whereby the trunk may sustain these forces.
                   In final summary, Davis concluded that there was evidence that
                two complementary mechanisms are in action when large flexion
                forces are resisted by the human trunk, these being the spinal
                column and its muscles on the one hand, and the "pneumatic"
                mechanism on the other. Each is affected by its own group of
                disorders, and in theory, it appears that the more flexed the
                trunk when lifting the more likely it is that damage will occur.

CITATIONS: Five references.

METHODS: A task-oriented approach has been taken instead of using indi-
vidual variables in predicting the weight that can be lifted.
The model consists of a base weight (WB), which is the maximum
(under some criterion) which can be lifted under perfect condi-
tions, multiplied by a series of factors to give the effects
of the task variables. For example, the weight lifting capa-
bility of females is about 60 percent that of males so that the
factor for sex would be 1.00 for males and .6 for females. The
model is given as:

Predicted weight in situation $j = W_p(j) = WB \prod_{i=1}^{\pi} factor_i(j)$

If the factors such as above affect the maximum weight lifted
in a variety of situations, the assumption that all other factors
act in the same way justify the above model.

An experiment to observe the effect of age on lifting non-
compact objects was conducted to test the model. A 20 inch
cube was used as the lifting object and was lifted into a carry-
ing position from the floor at increasing weights. The carrying
position was defined as the metacarpel phalangeal articulation
in the anatomical position and ranged from 704 to 823 mm above
the floor. The maximum weight chosen by each subject was
measured. Forty-five subjects (male) were chosen from five
to nine age groups. These age groups were five year inter-
vals from 15-20 years through 55-60 years.

In order to test the general structure of the model, five
subjects were given a random sample of conditions under which
to lift a load. The variables were sex, age, height of lift,
awkwardness of object. The subject's maximum weight in each
condition was measured in exactly the same way as in the experi-
ment. The model was used to predict the weight by multiplying
together all the factor values appropriate to each condition.

RESULTS: The analysis of variance applied to the weight chosen by the
nine age groups showed that age group was a significant effect.
Adjacent group means were significantly different. Mean weight
lifted was 30.8 kg (non-compact object was used), which appears
to be about 60 percent of the weight for compact objects.

In formulating the prediction model, a base weight of 100
pounds was chosen and the 50th percentile of the population was
given a factor value of 1.0. The regression equation was given
as:

    Actual weight = 0.967 (Predicted weight) + 3.5 kg

The correlation coefficient was 0.936, explaining 87.6 percent
of the variance of the actual weights.

The model predicted weight is consistently less than the
actual weight.

Drury & Pfeil, 1973 (continued)

SUMMARY: An attempt has been made to devise an empirical prediction model
of manual lifting performance, based on task factors rather than
individual factors. It was demonstrated that the effect of one
variable (age) is similar in a study of 45 subjects using a non-
compact object to that found in previous studies using compact
objects. A model is proposed to predict lifting performance
from a number of task variables. The model was tested using
the effects of 5 variables; estimated from the literature, the
correlation between the actual and predicted weight was found
to be 0.936, explaining about 87.6 percent of the variation.
 The model is built to find application in industry where the
industrial engineer or safety officer doesn't have enough details
about the individual variables to ensure that operations will
work within safe limits. This model gives practical limits with
task variables and the individual variables are covered by
specifying a particular percentile value in the model.

CITATIONS: Twenty-four references.

METHODS: This study consisted of 19 males lifting a container with
                different weight loads to various heights.   The subjects ranged
                in age from 17 to 28 and selected anthropometric dimensions
                were measured for comparison.   The subjects lifted the contain-
                er up two steps.   The steps were 32 inches wide, 18 inches deep and
                had two strips of wood placed 9½ inches apart to limit the area
                in which the container had to be placed.   The steps ranged in
                height from 1 foot to 7 feet with 1 foot increments.   The sub-
                jects had to lift the box with their entire back held straight
                at all times, but it did not need to be perfectly vertical.
                This required subjects to have their knees sufficiently bent
                to allow them to grasp the handle of the box while holding
                their arms straight.   The subjects then lifted the box off the
                ground by straightening their legs, and when they were in an
                erect position, they could then bend their arms and place the
                box on the step between the guide strips.   The test was run in
                three series.   In the first and third series, the subjects
                began lifting at the 1 foot level, whereas, in the second
                series, the subjects began lifting at the highest level they
                could.

RESULTS: The entire sample could lift up to 5 feet, with the lifting
                capacity for the 50th percentile at 5 feet being 57 pounds, at
                4 feet being 81 pounds, at 3 feet being 114 pounds, at 2 feet
                being 190 pounds, and at 1 foot being 231 pounds, (weights for
                the 5th, 25th, 75th, and 95th percentile at these heights are
                also given in this paper).   Nine subjects could lift to 6 feet
                with the mean weight lifted being 46 pounds and only one sub-
                ject could lift to the 7 foot level with a weight of 50 pounds.
                Fatigue decrements were not studied.

SUMMARY: Nineteen male subjects were used to test their weight-lifting
                ability.   They lifted weighted containers to various heights,
                ranging from 1 to 7 feet.   The subjects had to lift with their
                backs straight and also had to keep their arms straight until
                they were in an erect position so that the greatest share of
                lifting was done by straightening the knees and legs rather
                than by using the arms and trunk.   The author then concluded
                the following from the data: 1.   Weights could be lifted
                successfully by the entire sample to platforms from 1 to 5 feet
                above the floor, but not to 7 feet.   2.   Based on the fifth percen-
                tile values, the following weights are those which could be
                lifted by an adequate percentage of the sample at each level:
                1 foot, 142 pounds, 2 feet, 139 pounds; 3 feet, 77 pounds; 4
                feet, 55 pounds; 5 feet, 36 pounds.   3.   Only 9 individuals

                                        159

Emanuel, et al., 1956 (continued)

SUMMARY: (continued)
could lift any weight according to instructions to 6 feet
above the floor; and only one person was able to perform at
7 feet. Therefore, for tasks such as those considered in this
study, workers should not be required to lift weights higher
than 5 feet above the floor.
    The author also stated that the information about lifting
capacity at various heights could serve the following two
functions in work planning: 1. Tasks can be planned so that
a large percentage of young men can accomplish them. 2. It
can be estimated whether or not a particular weight lifting job
should be performed by machinery.

CITATIONS: Three references.

STUDY: Ergonomics Guide to Manual Lifting. American Industrial Hygiene
          Association Journal, 31(4), 511-516, 1970.

KEYWORDS: Task variables, environmental variables, human variables

METHODS: Ergonomics Guide is published to provide a service to industry
           to aid in the evaluation of work situations, such as, signifi-
           cant variables to consider.

RESULTS: The following significant variables must be considered in any
           manual material handling (lifting situation):
           Task variables: weight, size, configuration of the object;
             height, distance, rate, and rhythm of lift.
           Environmental variables: temperature, humidity and air flow;
             air contaminants and O_2 deficiencies.
           Human variables: age, sex, physique, fitness, and work position.
           The following points must be carefully reviewed:
           1. Ergonomics Data:
               A. Weight of lift - for females and males. Biomechanical
                   or psychophysical criteria.
               B. Frequency of lift - physiological and psychophysical
                   criteria.
               C. Application of data - the following sequencing should
                   be followed:
                   1. Explanation of anthropometric data.
                   2. Evaluation of the size and weight of the object
                       being lifted.
                   3. Evaluation of the frequency of lift.
           2. Characteristic Injuries:
               A. Back injuries - excessively heavy objects can cause
                   acute or chronic injury to the back.
               B. Abdominal hernias - various types of abdominal hernias
                   can occur.
               C. Accidents - approximately 25 percent of handling acci-
                   dents are due to lifting.
               D. Foot injuries - when heavy objects are lifted and
                   carried, there is a risk of injury to the foot bones.
               E. Aggravation of circulatory and respiratory disorders -
                   manual lifting involves the circulatory and respiratory
                   systems and the risk of aggravating them increases with
                   excessive frequencies of lift.
           3. Industrial Hygiene Practice:
               A. Industrial uses - manual lifting, occasional or repeti-
                   tive, is usually found with tasks such as lowering,
                   carrying, pushing and pulling.
               B. Evaluation of exposure - the weight of lift and fre-
                   quency of lift.
               C. Hazards and their recommended control -
                   1. Incorrect method of lifting - training.
                   2. Older workers - precautions in placement.
                   3. New workers - medical screening, training and
                       conditioning.

Ergonomics Guide to Manual Lifting, 1970 (continued)

RESULTS: (continued)
              C. 4. Stressing environments - proper clothing and breath-
                      ing.
                  5. Awkward working positions - proper work place design.
                  6. Unhealthy or pregnant workers - decrease the weight
                      lifted based on medical advice.

SUMMARY: This guide reflects the current state of the art in laboratory
              research and industrial experience, and is likely to be changed
              as new information becomes available. This is published as a
              service to industry to aid in the evaluation of work situations
              and to make them aware of ergonomic data, characteristic injuries,
              industrial hygiene practice, as well as significant variables
              to consider in manual lifting.

CITATIONS: Twenty-four references.

STUDY: Frederik, W.S. Human energy in manual lifting. Modern Materials
             Handling, 14(3), 74-76, 1959.

KEYWORDS: Manual lifting, energy consumption, weight, vertical range

METHODS: In this research, some of the factors governing manual lifting
             were evaluated and studied. Tests were run to determine the
             energy consumption for lifting weights ranging from 20 to 65 lbs,
             over a vertical distance of 20 in. in a height range from 0 to 20
             inches, 20 to 40, 40 to 60, and 60 to 80. The compounded results
             were presented on a graph.

RESULTS: The results indicated that the best area for manual lifting is
             between 40 and 60 inches from floor level for a standing man of
             average height, and that the ideal weight within the recommended
             area is about 40 lb. An arbitrary limit for the average hourly
             caloric output in sustained work was set at 200. From this limit,
             the maximum number of lifts a man could make under any of the
             conditions covered in the tests can be determined.

SUMMARY: An ideal weight and ideal vertical range have been devised for
             manual lifting. Lowered efficiency will result if loads greater
             or less than the ideal are lifted. If however, lifting cannot
             be performed in the ideal range, at least an ideal load can be
             determined for efficient lifting in the range required. If there
             is no control over weight or lifting range, the physiological
             limit on the rate of manual lifting can be determined.

CITATIONS: None cited.

STUDY: Garg, A. A metabolic rate prediction model for manual materials
            handling jobs., unpublished Ph.D. dissertation, The University
            of Michigan, 1976.

METHODS: Six subjects were selected for this study, three males and three
            females. Light, medium and heavy subjects were selected in both
            male and female categories to cover a wide range of body weight.
            All subjects were college students of 18 to 22 years of age and
            in good physical condition. An imbalanced factorial design was
            used. The following tasks were studied:

            1. Lifting and lowering: two vertical height ranges (floor
            to 32" and 32" - 60") were used for lifting and lowering loads.
            Two lifting techniques (stoop and squat) were used when lifting
            and lowering from floor to 32". Load levels of 6 lbs., 33 lbs.,
            44 lbs., and 55 lbs., and frequencies of 4, 8, and 12 lifts per
            minute were employed to measure the metabolic costs of lifting
            and lowering. For lifting, a one hand lift from the floor to a
            32" vertical height range was also studied.

            2. Holding, walking, and carrying loads: four techniques
            were used for holding and carrying loads; load held at arms
            length against thighs (both hands), load held against waist
            (both hands), load held at arms length at sides (both hands),
            and load held at arm length at side (one hand). The load weights
            employed were 0 lbs., 33 lbs., and 55 lbs. for the first three
            techniques and 0 lbs., 16.5 lbs., and 27.5 lbs. for one hand at
            the side. Subjects walked at speeds of two and three miles/hour
            in a corridor on a finished concrete floor.

            3. Horizontal work: Movement of arms was in the sagittal
            plane at bench height (32"). Four different body postures were
            employed; both hands (standing), one hand (standing), both hands
            (sitting), and one hand (sitting). The horizontal movement of
            arms from the edge of the bench was 24" and 16" for standing
            and sitting postures, respectively. Load weights were 6 lbs.,
            33 lbs., (both hands, standing); 6 lbs., 16.5 lbs., (one hand,
            standing); 6 lbs., 22 lbs., (both hands, sitting); and 6 lbs.,
            11 lbs., (one hand, sitting). Frequencies of four and eight
            lifts per minute were employed.

            4. Lateral arm work: different loads and frequencies were
            employed.

            5. Pushing: Two height levels were employed, 32" (bench
            height) and 60" (chin height). The total distances of pushing
            were 24" and 16" at the bench and chin height, respectively.
            Average pushing forces were 7 lbs., and 26 lbs. at bench height
            and 3 lbs., and 23 lbs. at chin height. The pace employed for
            pushing the load was four and eight times per minute.

164

Garg, 1976 (continued)

RESULTS: (continued)
    Energy prediction models using stepwise regression analysis
were developed for the tasks studied. The correlation coeffi-
cients and coefficients of variations were 0.98 and 0.08,
respectively. Results also showed that most of the variation
(80% - 97%) in net metabolic cost of task with a given technique
could be explained by first order interactions of body weight
and load with the frequency of loading the body.

SUMMARY: The objective of this research was to develop a model to estimate
metabolic energy expenditure rates for a wide variety of manual
materials handling jobs. The model was based on the assumption
that a job could be divided into simple tasks and that the
average metabolic energy expenditure rate of the job could be
predicted by knowing the energy expenditures of the simple tasks
and the time duration of the job. Over 540 oxygen uptake measure-
ments were made for different variables on six subjects (3 males
and 3 females, 18-22 years of age and 122-200 lbs. of body weight).
Prediction equations for the net metabolic energy expenditure
rate of each task as a function of personal and task variables
were developed via stepwise, forward, least square error regres-
sion analysis.

CITATIONS: One hundred thirty one references.

STUDY: Goldman, R.F. & Iampietro, P.F. Energy cost of load carriage. Journal of Applied Physiology, 17(4), 675-676, July 1962.

KEYWORDS: Energy cost, grade, load, speed

METHODS: Ten men acted as subjects for the study. The subjects walked on two large (4-man) treadmills which were set at a given grade (3 percent, 6 percent, or 9 percent) and speed (1.5, 2.5, 3.5, or 4 mph). Three standard loads were selected and made up on packboards so that the total weight of load and packing was 10, 20, or 30 kg.

Duplicate Tissot collections of expired air were taken on each subject during the last 15 min. of a 45 min. walk, and oxygen concentrations were measured with a Beckman paramagnetic O_2 analyzer.

Subjects were ranked with respect to percentage of body fat so that the five subjects studied for a given condition represented a cross-section within the relatively narrow range of body fat presented by the group.

RESULTS: The results show that energy cost per unit weight (subject weight plus loads of 10-30 kg) is a constant for a given grade and speed. The following curve-fitting formula was evolved relating progression rate, load, and grade over the ranges 1.5-4.5 mph (S), 0-30 kg load (L), 0-9 percent grade (G).

$$\text{Energy cost (70 kg subject, in kcal/min.)} = 4.3 - 1.1S$$
$$-.22S^2 - 6.3G + 8.2GS - .05GS^2 + 3.6G^2S^2 + 4.06LG$$
$$-1.77LGS + .003LS^2 + .24LGS^2 - .06LG^2S^2$$

Calculations of predicted values for energy cost from this formula are in close agreement with observed values.

Variations in such parameters as stature, stride, physical condition, and skill in adjustment of a load all influence the energy cost of progression. For this reason the energy estimates must be regarded as first approximations. It seems probable that for a given rate of progression and grade, the energy cost per unit weight is essentially the same, regardless of the distribution of total weight between body weight and load within the range 0-30 kg load for a reasonably fit individual.

SUMMARY: The relative contributions of rate of progression (1.5-4 mph), grade (3-9 percent), and load (10-30 kg) to total energy cost were determined. The data obtained were integrated graphically with some of the available-energy cost data in the literature to provide a useful graph for estimating energy expenditure. It was tentatively concluded that for grade walking over the ranges studied, the energy cost per unit weight is essentially the same whether the weight is of the body or the load.

CITATIONS: Three references.

STUDY: Haisman, M.F. & Goldman, R.F.   Effect of terrain on the energy
           cost of walking with back loads and handcart loads.   Journal
           of Applied Physiology, 36(5), 545-548, 1974.

KEYWORDS: Work, manpower assists, load carriage, terrain coefficient

METHODS: Eight soldiers participated in the study. Their characteristics
           were: nude weight, 75.3+11.5 kg; height, 177.2+2.5 cm; age,
           20.9+1.7 years; percentage body fat content, 15.7+4.3 percent.
           Each subject performed 24 30 minute walks for each of the follow-
           ing conditions: four loads-20 kg carried on the back or 20, 60,
           or 100 kg cart loads; three terrains-black top for road, dirt
           road, and grassland; two walking speeds - 0.89 and 1.34 meters/
           second. The basic cart weighed 20 kg; the overall length was
           183 cm, and the axle width was 89 cm; two other carts (identical)
           were loaded to 60 and 100 kg. Cart balance was checked daily,
           with a spring balance, to require an upward lift on the handle
           of 2.3 kg at a height of 1 m. Tire pressures were maintained
           at 21 newton/cm^2. Average ambient temperatures during the
           study were 19.6°db and 15.7°wb.
              Energy expenditure was measured by means of Max Planck
           respirometers for three periods of 5 or 6 minutes, with the
           collection periods ending at 10, 20, and 30 minutes. Heart
           rates were counted by palpation of the radial artery immediately
           before and after each walk.

RESULTS: The following observations were made:
           1. At both speeds, energy costs on blacktop show relatively
               little increase with cart weight. However, energy costs
               on both uneven terrains increase markedly with increasing
               cart weight and only the 20 kg cart is equivalent to a
               20 kg back load.
           2. The slopes of energy cost and cart weight are only approxi-
               mately linear.
           3. Energy cost expressed by kg of total weight of the man
               and his back load allowed the same general observations
               as the gross energy cost results.
              Heart rate increments show the same overall pattern as the
           energy cost results but with much greater variability. Terrain
           coefficients illustrate the reasonably good agreement between
           speeds for each terrain, except for the 60 kg cart on grass.
           Energy cost for the 100 kg cart is increased by 1.31 on the
           dirt road and 1.44 times on the grass compared to the same
           activity on black top.
              With terrain coefficients of 1.0 for blacktop and 1.1 for
           dirt road, energy cost was predicted from body and load
           weight and speed. The predicted values overestimated energy
           cost on the fast speed and underestimated on the slow speed.
              Net energy cost of cart pulling was obtained by subtracting
           the calculated cost of walking from the total cost of cart
           pulling. The four carts (each of a different design) show
           a wide spread of net energy cost. It appears that cart design
           has more effect on energy cost than cart weight.

167

Haisman & Goldman, 1974 (continued)

SUMMARY: Eight young soldiers carried a 20 kg back load or pulled a
hand cart weighing 20, 60, or 100 kg, at two speeds (0.89 or
1.34 m/sec.) on three terrains (black top road, dirt road,
or grassland) in a randomized factorial design. Energy cost
was measured three times during each 30-minute walk. The
results indicated that although on a smooth surface the 100 kg
cart was more costly than a 20 kg back pack, on both uneven
terrains only the 20 kg cart was equivalent to a 20 kg back
load. Nonetheless, the energy cost of moving the 100 kg cart
over these uneven terrains, at these speeds, was within accept-
able physiological limits for these subjects. This would pro-
bably not be true with more difficult terrains such as soft
sand or heavy brush.

CITATIONS: Thirteen references.

STUDY: Haisman, M.F., Winsmann, F.R. & Goldman, R.F. Energy cost of pushing loaded handcarts. Journal of Applied Physiology, 33(2), 181-183, 1972.

KEYWORDS: Work, manpower, assists, load carriage

METHODS: Seven soldiers acted as subjects in this study. Each subject performed one 30 minute walk at 1.56 m/s (3.5 mph) with one cart on the treadmill and one walk with another cart on the outside circuit. Energy expenditure was measured three times during each 30-minute walk. Tissot spirometers were used for the treadmill walks and Max Planck respirometers for outdoors. The total weight of clothing and respirometer was about 7 kg. O_2 and CO_2 concentrations of the expired air samples were determined by use of a Beckman E-2 oxygen analyzer and a Beckman LB-1 CO_2 analyzer. Two treadmills were used; each was large enough to accommodate a subject pushing a handcart.

The four handcarts were loaded to achieve a total weight of 50 kg. These carts were obtained commercially and were different from each other. Ambient temperature was controlled in the treadmill chamber, mean db $22.2\pm0.7°C$, mean wb $15.2\pm1.2°C$ and wet bulb $11.8\pm6.2°C$. Identical clothing was worn inside as well as outside.

RESULTS: Mean values of energy expenditures for the treadmill and the outdoor circuit closely agreed. Cart A (4 wheeled mail carts) had the lowest values and Cart D (golf carts) the highest; the differences between carts were significant except between A and B (large garden cart.). Analysis of the energy expenditure data, standardized for total body weight by dividing each energy cost by the total weight of the man, his clothing, and respirometer, showed the same pattern of results.

The mean value of energy expenditure for all carts for the treadmill walks was $511\pm52(sd)w$, which was close to the mean for the outdoor circuit $512\pm45w$.

SUMMARY: Seven male volunteers, mean age 21 years, pushed four types of handcarts at 1.56 m/s, on a level treadmill and on an outdoor asphalt circuit. The carts (A, four wheel; B.C.D., two wheel) had the following wheel diameters: A, rear 30 cm, front 15 cm; B, 50 cm; C, 40 cm; D, 35 cm. Each cart was loaded to achieve a total weight of 50 kg. Force measurements of energy expenditure were made during each 30-minute walk. The mean value for all carts for the treadmill walks was $511\pm52(sd)w$, which was closely similar to the mean for the outdoor circuit $512\pm45w$. Cart A was found to require the lowest energy expenditure, $478\pm37w$, and Cart D the highest, $555\pm41w$.

This study attempts to determine the most economical means of carrying heavy loads, in terms of minimal energy cost to the human body and could be useful in developing design criteria for handcarts.

CITATIONS: Ten references.

KEYWORDS: Work pace, load weight, physiological stress, heart rate, and
           energy expenditure.

METHODS: Heart rate and oxygen consumption were used to measure the
           physiological stress of six male subjects as they were performing
           experimental tasks of carton handling. The variables in this
           experiment were load weight and work pace. There were four
           levels of load weight (10 lbs., 15 lbs., 20 lbs., and 25 lbs.)
           and work pace (6, 9, 12, and 15 cartons per minute). All six
           subjects performed the 16 prescribed combinations. Then work
           output was obtained for each subject at all 16 levels.

RESULTS: Work pace and load weight were found to be linear in their
           effects on energy expenditure rate and heart rate. The existence
           of a linear relationship indicates that no optimum work pace
           exists, using these measures of effort, for the experimental
           tasks over the range of work paces studied. Also, the inter-
           action of pace and weight was found to be significant in its
           effects on energy expenditure rate and heart rate. The inter-
           action, however, of pace and subjects was found to be significant
           for energy expenditure, but not for heart rate.

SUMMARY: Physiological stress of six male subjects was measured as each
           performed various combinations of experimental tasks of carton
           handling where the variables were load weight and work pace.
           The results indicated that the design of the job is a significant
           factor in determining the physiological cost to the worker. Also
           the following guideline is offered for job design:
             Use heavier weights at slower paces. Pace and subjects were
           found to be significant in their effects on energy expenditure
           but not for heart rate, whereas pace and weight were found to
           be significant in their effects on both.

CITATIONS: Eighteen references.

STUDY: Jones, D.F. Back strains: the state of the art. Journal of
            Safety Research, 3(1), 28-34, 1971.

KEYWORDS: Back strains, lifting techniques

METHODS: The history of manual lifting techniques and resulting stresses
            in components of the human trunk are reviewed. Papers by
            Bradford and Spurling (1975) and Bartelink (1957) are utilized
            to develop a new hypothesis reflecting the interacting role of
            the three mechanisms of lifting (spine, muscles, intra-abdominal
            pressure) to stimulate further research in this field. The
            hypothesis is based on the idea that the body during lifting
            is more than a simple crane; actually it is a complex crane with
            a hydro-pneumatic device installed below the boom. This hydro-
            pneumatic device is created by the abdominal pressure in the
            abdominal cavity.

RESULTS: The hypothesis, as presented, places known facts in a relationship
            which appears to fit the human body more accurately than explana-
            tions previously advanced. Jones states that the human body is
            more complex than the crane we have used to describe it for many
            years, and that lifting involves dynamic as opposed to static
            forces.
              The technique of lifting that each individual finds most suit-
            able is the safest for him, and our efforts should be directed
            at emphasizing the need for conditioning of stomach muscles and
            the neuro-muscular responses necessary for coordinated movement.
            Also, we should explain to workers the unstable positions, the
            role of momentum, fatigue, and moment.

SUMMARY: After reviewing literature on manual lifting techniques and re-
            sulting stresses, Jones offers a hypothesis of lifting that em-
            phasizes the dynamic aspects of lifting as compared to previous
            static explanations previously offered. This hypothesis could
            result in a re-assessment of the tendency to minimize manual
            involvement in tasks. Further, it could explain unstable posi-
            tions, the role of momentum, fatigue and moments, and the bene-
            fit of maintaining the resultant of forces below and in front
            of the lumbar spine. Jones proposes that a more complex model
            be developed including a hydro-pneumatic cylinder and back
            muscles which can be lengthened or shortened independently to
            illustrate the effect of poor coordination on the stability of
            the spine.

CITATIONS: Seventeen references.

STUDY: Jones, D.F. Back injury research: a common thread.
         American Industrial Hygiene Association Journal, 33 (9),
         596-602, 1972.

KEYWORDS: hip-flex, kinetic, mechanical, dynamic.

METHODS: The contention is made that back pains have nothing to do
           with the working environment (i.e., the external conditions).
           Therefore, it is necessary to review some basic principles
           to determine the etiology of back pains. The analogy which
           compares the vertebral column with a crane provides the frame-
           work by which various lifting techniques could be analyzed.
           More specifically, this paper compares the hip-flex, kinetic,
           natural, mechanical, and dynamic lifting models with the
           supposition that the vertebral column is dynamically comparable
           to the crane.

RESULTS: A comparison of the aforementioned lifting methods made pos-
           sible an analysis of the differences between utilizing the
           trunk like a "fishing pole" or a relatively rigid cylinder
           when lifting a load. For example, the natural lifting method
           entails lifting a load with a horizontal back (analogous to a
           fishing pole), and the kinetic method dictates that the back
           be maintained as straight as possible with a stable trunk
           (analogous to a rigid cylinder). Although the natural lifting
           method is found not to consume as much energy as any of the
           back straight-knees bent methods, it does impose a greater
           stress on the vertebral column when heavy loads are lifted.
               Anatomical evidence indicates that the vertebral column is
           laterally and frontally supported by muscle groups. In light
           of this, the foregoing lifting models stress that in attempting
           to change the relative position of adjacent vertebrae under
           load, a worker may readjust the muscles out of sequence or
           create a temporary weakness in those supporting muscles; the
           resultant lateral movement of the vertebral column would
           cause back pain.

SUMMARY: In essence, the report supposes that it is usually not the
           external force (i.e., the load per se) which causes back
           injury, but the body's reaction to it. It is the coordinated,
           sequential adjustment of the vertebrae, along with the sup-
           porting muscle groups that will preclude back injuries. This
           evidence implicates the importance of training, especially
           before attempting to lift heavy loads. More specifically,
           the lifting techniques commonly advocated stress training in
           stabilizing the spinal column through stabilization of the
           entire trunk.

CITATIONS: Fifteen references.

METHODS: Seventy-nine experiments on repetitive lifting of burdens from floor to table have been performed with 4 female and 4 male subjects. For each subject the maximum burden which could be lifted from floor to table height using a correct lifting technique and the maximum oxygen uptake were determined. From the maximum burden which could be lifted, relative burdens of approximately 10 percent, 25 percent, 50 percent and 75 percent were calculated. Each of the eight subjects lifted the calculated weights under three different frequency conditions. The lifting procedure lasted 20 minutes, during which the oxygen uptake and pulse rate were measured. The maximum lifting frequency, which did not demand more than 50 percent of the subjects maximum oxygen uptake, was determined for each relative burden on each of the subjects. These maximum lifting frequencies for all subjects and all relative loads were then plotted against relative burdens.

RESULTS: The maximum lifting frequency of females is approximately 0.7 of that of males at the same relative burden. The difference is probably due to the difference in the capacity of the oxygen transporting system in the two sexes. The load on the circulatory system in lifting and in leg work on a bicycle ergometer was compared by investigating the pulse rate/oxygen uptake relation. It was found that the orthostatic load on the organism was most pronounced when lifting heavy burdens at low frequencies. The efficiency of useful work in lifting was found to be approximately 6 percent.

SUMMARY: Earlier investigations have demonstrated that the back muscle strength is the limiting factor when a single lift is performed. This experiment, however, showed that in repetitive submaximal lifting both the capacity of the oxygen transporting system and the muscle strength in the back act as limiting factors if the accepted physiological limits are not exceeded. Thus, from an ergonomic point of view, it is necessary to know the strength in the back muscles of the worker as well as the maximum oxygen uptake per kg body weight. This should be kept in mind when planning a work place where repetitive lifting is performed.

CITATIONS: Twelve references.

STUDY: Kamon, E. & Belding, H.S. The physiological cost of carrying
           loads in temperate and hot environment. Human Factors, 13(2),
           153-161, 1971.

KEYWORDS: Cartons, grade, metabolic cost, heart rate (HR)

METHODS: This study was concerned with the physiological cost of carrying
           bulky cardboard cartons; both metabolic cost and HR were mea-
           sured. Three subjects, who were pretrained and preacclimatized
           by 10 days of daily walking for 2 hours at 3.5 mph at 45°C,
           were used. The load was a cardboard carton (40*30*30 cm),
           weighing 10, 15 or 20 kg. One of the three thermal conditions
           prevailed in the chamber: neutral, dry bulb (D.B.) 20°C, wet
           bulb (W.B.) 15°C; warm-dry, 35°C (D.B.), 20°C (W.B.); or hot-
           dry, 45°C (D.B.), 25°C (W.B.). Air speed was about 75 m/min.
           In a single experiment, one of four combinations of speed and
           grade was employed. Speed was 4 or 5 km/hr, grade was 0 to
           4 percent.

           HR was recorded continuously by an electrocardiogram over
           the second half of each minute throughout each experiment.
           Douglas bags were used to collect expired air during the last
           2 minutes of each period of the first and third cycle. A
           Beckman paramagnetic oxygen analyzer (Model C_2) was used to
           measure oxygen concentration.

           The subject was dressed in shorts, rubber shoes and socks.
           After the subject was hooked up, he sat quietly for about 15
           minutes during which resting HR was recorded. Each test last-
           ed for 65 minutes. After entering the chamber, the subject
           sat down for 5 minutes and then warmed up by walking for 10
           minutes at the speed and slope designated for the test. After
           a second rest of 5 minutes, he went through 3 cycles, each
           divided into three 5 minute periods. Cycle 1 - walking, carry-
           ing the load, sitting; cycle 2 - carrying the load, walking,
           sitting; cycle 3 - same as cycle 1.

           The load was placed on a waist-high shelf at the front of
           a motor-driven treadmill. The subject was asked to lift the
           load away from the shelf while walking. After carrying the
           load for 5 minutes in both hands, he placed it back on the
           shelf while walking.

RESULTS: The metabolism per meter walked was least at speeds between 65
           and 85 m/min. The ambient temperature did not affect the
           metabolic cost and so the results for all three thermal condi-
           tions were averaged for each load at each speed and grade. Ten
           kg loads added substantially to the metabolism of walking at
           any of the four combinations of speed and slope. Loads of
           15 kg usually required an increase in metabolism proportional
           to the added weight. The 20 kg loads had different effects on
           metabolism, depending on the subject and the speed-grade com-
           bination. For all three subjects, the smallest relative in-
           crease in metabolic cost attributable to the load was found at

174

Kamon & Belding, 1971 (continued)

RESULTS: (continued)
4 km/hr with 4 percent slope. Without load, the energy cost
for the shorter of the two subjects of similar body weight was
greater. However, when metabolism was expressed in calories
per step, the difference between the two subjects nearly dis-
appeared. The heaviest and tallest subject had a higher meta-
bolic cost for walking. Carrying the load in the hands in
front of the body increased both step frequency and metabolic
cost. The extra cost of carrying load indicates an efficiency
loss, which was greater for heavier loads.

At 20°C, HR for each level of activity levels off, with
similar increments for each cycle. Under warmer conditions
this pattern changes. At 35°C, the leveling off is delayed
and the levels of HR reached are progressively higher for each
cycle. At 45°C, steady states were not attained during the
last two cycles either while working or resting.

A high degree of linear correlation independent of individual,
treadmill slope, speed of walking, and weight of load, but de-
pendent on ambient temperature was indicated in the regression
analysis. The regression of heart rate on metabolism is a
little steep at the two higher temperatures. These differences
in slope would have been accentuated if HR data from the third
cycle had been chosen.

SUMMARY: Cartons weighing 10, 15 and 20 kg were carried by hands in
front of the body at speed of 4 and 5 km/hr on level and
4 percent grade at dry ambient temperatures of 20, 35 and 45°C.
Three subjects were used; each test involved three 5 minute
periods of carrying the load, walking without the load and
sitting. At each speed, step rate increased with increase in
the weight of the load. The work efficiency decreased. The
metabolic cost for each kg of load carried was 1.3 to 2.3 times
greater than the cost per kg of body weight without load. Meta-
bolic costs were not significant under the three thermal condi-
tions, but HR increased by 7 to 10 beats/min for each 10°C
rise in temperature.

Based on considerations of metabolic and cardiac cost, fatigue,
and need for rest periods, 15 kg packages were determined to be
preferable to 10 and 20 kg packages for moving large amounts of
material by hand.

The study provides useful information in establishing lifting
standards under hot environment.

CITATIONS: Fifteen references.

175

METHODS: A weight of 5 kg was lifted to a level of 12 cm higher and back
          again (from 63 cm to 75 cm) at the rate of 30 cycles/minute.
          In the experiments with paced work, the subject followed the
          signals of the metronome. In rhythmic work, the subject carried
          out a predetermined number of lifts at a rate chosen by him-
          self, starting every 30 seconds and resting at the end of
          each sequence of lifts. The ventilation was measured during
          the experiments which lasted 10 minutes. The O_2 content of
          the expired air was determined by using the Beckman O_2 analyzer.
          The heart rate was counted by feeling the radial pulse during
          the work. The action potentials of some muscles of the trunk
          and upper limbs were recorded using surface electrodes. Four
          young adult male subjects were used.

RESULTS: When the work was interrupted into sequences of 10 lifts each,
          starting a sequence every 20 seconds, and carrying it out at a
          freely chosen pace, the energy expenditure per lift was consid-
          erably less than that used for performing the same work at a
          steady pace of 30 lifts/minute. Electromyographic recordings
          with the aid of surface electrodes demonstrated that the change
          from paced to rhythmic work involved major changes in the pat-
          tern of the motor innervation of both trunk and upper arm
          muscles, e.g. the number of action potential in m longiss-
          mus in rhythmic work was less than half that in paced work.

SUMMARY: This study shows that breaking the lifting work in short se-
          quences increases its mechanical efficiency. Although the task
          was very much the same in paced and rhythmic work, the partici-
          pation of various muscle groups in its performance showed wide
          differences. The electromyographic patterns differed at each
          site of recording and according to the character of the work.
          The electromyographic results emphasize that breaking a paced
          work in a series of rhythmic sequences is sufficient to alter
          the pattern of the innervation of the participating muscle
          groups deeply. The results of this study indicate that purely
          mechanistic concepts have only a limited application to the
          problems of light manual work. The energy cost of even a
          simple type of work cannot be predicted on the basis of general
          considerations, without exactly defining the rate and rhythm
          of working.

CITATIONS: Two references.

KEYWORDS: Optimum weight, optimum dimensions.

METHODS: In this study, the processes of tulip bulb handling and
             the requirements of the container for the bulb-growing industry
             had to be outlined and then the selection of an optimum size
             and shape container had to follow those guidelines. In the
             actual experiments, three weights were compared (8.75 kg.,
             17.5 kg., and 35 kg.). The influence of shape was eliminated
             by using the same shape basket for all weights. The task
             consisted of carrying 210 kg. of flower bulbs a distance of
             12 m., i.e., in lots of 35 kg. (six times), 17.5 kg. (12 times)
             and 8.75 kg. (24 times). Heart-rate was recorded continuously
             during each experiment and used as an index of work-load. The
             second test required the subjects to carry containers loaded to
             the same weight, but different sizes and shapes, a distance of
             360 m. at a constant speed of 90 m./minute. The subjects
             were then asked to tell which container was most convenient
             to carry.

RESULTS: When the subjects were loaded with 8.75 kg., they had the
             highest average heart rate frequency, whereas there wasn't
             much difference when they were loaded with 17.5 and 35 kg.
             When loaded with 35 kg., the subjects had the lowest heart-
             rates, but it showed a tendency to increase throughout the
             task instead of reaching a steady state. Consequently, 17.5 kg.
             was selected as the optimum weight. The optimum container was
             one that was long and narrow, and due to its small width, its
             center of gravity was close to the axis of the body, so that
             it is not strictly necessary to lean the body backwards for
             maintaining equilibrium.

SUMMARY: This article deals with an investigation into the optimum
             size and shape of a container and the transport and storage
             of bulbs in the Dutch Flower Bulb industry. The results of
             the investigations (both from the working and psychological
             point of view) were that the optimum weight for untrained
             people is 17.5 kg. and the optimum dimensions are 100 x 30 x
             12 cm. To further facilitate the carrying of the containers,
             it was suggested that a strap around the neck be used.

CITATIONS: Six references.

STUDY: Konz, S.A. and Bhasin, R. Foot position during lifting.
               American Industrial Hygiene Journal, 35(12), 785-792, 1974.

KEYWORDS: Tote box, acceleration, vertical, frontal, lateral force, cart-
               wheel, somersault torque

METHODS: The subjects lifted and lowered a 16.5 x 13 x 6 in. tote box
               filled with sand to 11 lbs. The center line of the box was
               18 in. from the body center line (assumed to be perpendicular
               from the earhole of the subject) at the lower position. At
               the upper position it was 34 in. from the original body
               center line. The subjects stood on a force platform while
               doing the task; the platform measured vertical force, frontal
               force, lateral force, cartwheel torque, and somersault torque.
               Vertical acceleration of the box was also measured. Lifting
               and lowering were measured at four conditions: 1) feet aligned
               and the upper shelf straight ahead; 2) feet aligned with the
               upper shelf at 45° angle to the right; 3) left foot ahead with
               the upper shelf straight ahead; and 4) left foot ahead with the
               upper shelf at a 45° angle to the right. In all four conditions
               the foot center lines were 9 in. apart.

RESULTS: 1. Experience: given the overall pattern in the data from
               the experiment as well as from previous experiments, it seems
               clear that peak forces increase with experience. This may
               be due to initial caution of the subject being reduced.
               2. Acceleration of the box: acceleration is positive when
               upward or deceleration is downward. It is negative otherwise.
               There is little difference among the four conditions.
               3. Vertical force: at any specific time in the lift, a typical
               range among the four conditions for the mean of eight subjects
               was 10 lbs.
               4. Frontal force: perhaps the most noticeable effect is the
               generally low magnitude of the forces. There is no appreciable
               difference among the four conditions.
               5. Lateral force: forces are lower than either vertical or
               frontal forces, with little difference among conditions.
               6. Cartwheel torque (torque about the frontal axis) during
               lifting and lowering was different among the four conditions.
               Some recommendations are:
                 i.   for straight-ahead lifting, keep feet aligned.
                 ii. for lifting with a turn, lead with the opposite foot.
                 iii. for straight-ahead lowering, keep the feet aligned.
                 iv. for lowering with a turn, lead with the opposite foot.
               7. In the somersault torque (torque about the lateral axis
               during lifting and lowering) for lifting, there is no appreciable
               difference among the four conditions. The previous rule
               of "lead with the opposite foot only when turning" reduces
               peak torque about 100 in -lb. and the reversal by about 100 in-lb.
               For lowering, the curves differ during the early part of the
               move but are the same during the latter portion. Leading with

178

Konz & Bhasin, 1974 (continued)

RESULTS: (continued)

the opposite foot only when turning reduced peak torque about 100.

Note that, although the torque may be the same for different foot positions, the stress on specific muscles may vary, depending on the lengths of different moment arms. Moving the foot forward 9 in. should give a better (longer) moment arm, so the resulting stress on the muscles and ligaments should be less. This would extend the advantage of leading with the opposite foot when turning. For workers there are thus two pieces of advice:

1. When lifting or lowering straight ahead, align the feet.
2. When turning, have the foot on the side opposite to the turn ahead.

SUMMARY: Approximately 25 percent of compensable industrial injuries are due to incorrect handling of materials; from a safety viewpoint the problem is overstress on muscles and ligaments rather than strain on the cardiovascular system. Eight (8) male subjects lifted and lowered an 11 lb. box at four conditions stated in methods above. Forces were measured with a force platform. When lifting or lowering straight ahead, align the feet. When turning, have the foot on the side opposite the turn ahead. Forces were very "peaked;" peak force on the vertical axis was 60 lbs.

CITATIONS: Seven references.

STUDY: Konz, S. & Desai, G. Lifting forces for nine lifting heights.
            III Symposium International de Posturographic Paris, September
            23-26, 1975.

KEYWORDS: Peak force, peak torque, peak lateral force, somersault torque,
            cartwheel torque.

METHODS: Two male subjects (height: 174 cm, weight: 66kg) stood on a
            force platform and lifted a 5 kg box to height of 15, 30, 45,
            60, 75, 90, 105, 120, and 135 cm. The center of mass of the
            box was 40 cm from the center of mass of the subject. Each
            subject lifted 12 times at each condition. Since the study
            was safety oriented rather than energy oriented, the peak
            forces or torques for each axis were the criteria rather than
            the area under the curve.
                Stage I (0 to 1.3 seconds) ends with the grasping of the box;
            stage II (1.3 to 3.7 seconds) ends with the box on the shelf;
            stage III (3.7 to 5.0 seconds) ends with the subject standing
            vertically. The vertical force is the dominant force.
                Each of the nine heights was a condition. Two random sequences
            of the nine conditions were generated. Each subject followed
            one of these sequences and then to counterbalance serial effects,
            the same sequence in reverse order. At each condition, each
            subject made three lifts. Thus there was data for six lifts/
            subject at each condition.

RESULTS: The vertical force peaks are greater than object weight due
            primarily to the effect of the body weight, but also due to
            acceleration. Height of lift did not significantly affect
            the peak values. In stage I, peak A (-8.7 kg) occurs at .6
            seconds and peak B (+4.8 kg) occurs at 1.1 seconds. In stage
            II, peak C (-4.4 kg) occurs at 1.6 seconds; peak D (+12.7 kg)
            occurs at 2.2 seconds; and peak E (-6.3 kg) occurs at 3.0
            seconds. There is no discernible peak in stage III.
                Peak lateral force was 3 kg. Mean peak twist torque was
            .17 kg-m. Mean peak somersault torque was 4.40 kg-m. Mean
            peak cartwheel torque was 6.25 kg-m.

SUMMARY: When investigating the characteristics of safe lifting it is
            important to use the proper criterion. The part of the body
            injured is the skeletal-muscular system, not the cardio-
            vascular system. What is important from a safety viewpoint, is
            the stress in relation to the capability over a short time
            period (less than 5 seconds).
                This study investigated only the final location of the object
            to be lifted and then only for two-handed sagittal plane lift-
            ing. The criterion was output from a force platform.

CITATIONS: Seven references.

180

METHODS: Five male students, between the 40th and 60th percentiles of
               height, acted as subjects in the study. Their weight ranged
               from 150-170 lbs. with a mean of 157. During the experiment,
               the subject stood on a 6-axis force platform, which resolved
               the forces and torques into their six components (vertical,
               lateral, and frontal forces; and twist, somersault, and cart-
               wheel torques). A wooden tote box containing sand was lifted
               with both hands from a shelf 42 inches high. One variable was
               the weight of the load. A 16.5 x 13 x 6 inch container with
               hand grips was filled to 11, 22, or 33 lbs. with sand. The
               second variable was the distance (16, 18, or 20 inches) be-
               tween the center of the load on the lower shelf and the rear
               of the heel of the subject's foot. The third variable was the
               angle of the turn (the shelf was located directly ahead, at
               45° or 90° to the left). A cube design was used with the 15
               experimental conditions. Each subject lifted four times at
               each condition in each of the two replications. A 10 second
               rest was given between conditions. During the rest period
               between conditions, the subject was lying down.

RESULTS: Replications did not produce a significant effect on any of the
               six criteria, so all the means are based on the 40 values for
               each condition (5 subjects x 4 performances per replication x
               2 replications). The mean peak force along the vertical axis
               over all distances was 50.6 lbs. The effect for weight was
               significant but the effects for angle and the interactions were
               not. The   in peak force along the frontal axis was 17.5 lbs.
               The distance did not have a significant effect. The effects
               of weight, angle and their interaction were significant. The
               mean peak force along the lateral axis was 5.9 lbs.   Again
               the distance did not have a significant effect. The effects
               of weight, angle, and their interaction were significant.
                 The mean peak twist torque over all distances was 156 in-lbs.
               Effect of angle and weight were significant. The mean peak
               cartwheel torque over all distances was 401 in-lbs. Again
               the effects of weight and angle were significant. The mean
               peak somersault torque was 680 in-lbs. The effect of angle was
               not significant, but those of distance and weight were.

SUMMARY: A force platform was used to study the effect of the following
               variables on lifting: distance of the load from the heel (16,
               18, or 20 inches), weight of the load (11, 22, or 33 lbs.), and
               angle of turn (0, 45, and 90°). Five male students, between
               the 40th and 60th percentile in height, lifted eight times at
               each condition. The mean peak force was 50.6 lbs. along the
               vertical axis, 17.5 lbs. along the frontal axis, and 5.9 lbs.
               along the lateral axis. The corresponding mean peak torques

Konz, et al., 1973 (continued)

SUMMARY: (continued)
             were 156 in-lb. for the twist, 401 in-lbs. for the cartwheel,
             and 680 in-lb. for somersault torques. Object weight has a
             significant effect on all six criteria. The effect varied in
             relation to the weight of the body plus object more closely
             than to the weight of the object alone. Angle of turn had a
             significant effect on all criteria except somersault torque.
             Distance did not have any significant effect on any criteria
             except somersault torque.

CITATIONS: Thirty-eight references.

STUDY: Kroemer, K.H.E. Human strength: terminology, measure-
             ments, and interpretation of data. Human Factors, 12(3),
             297-314, 1970.

KEYWORDS: Isometric, isotonic, static strength, dynamic strength,
             concentric effort, eccentric effort.

METHODS: This paper presents a comprehensive review of some of the
             problems encountered by human engineers when attempting
             to apply strength data to human engineering problems. The
             etiology of these problems centers on the ambiguous ter-
             minology and data used among various researchers which
             hampers the interpretation of experimental data and its
             application to the dynamic and real-world situations.
             Consequently, this paper provides the reader with the
             terminology found within the discipline of human strength
             testing, along with definitions, measurement techniques,
             and interpretation and application of strength data. Fur-
             thermore, it attempts to establish a relationship between
             human static force capabilities and dynamic forces.

RESULTS: The clarification of the extant ambiguities in both the
             terminology and data revealed that strength data are
             fully relevant to human engineering problems only when
             the worker exerts maximal static muscle force; the exer-
             tion of submaximal forces in certain tasks limit the appli-
             cability of strength data.

SUMMARY: This paper attempted to solve some of the problems con-
             cerning the use of ambiguous terms and data in the human
             strength testing discipline. It pointed out the general
             lack of standardization effect on the comparison and inter-
             pretation of results in strength studies conducted by
             various researchers. The paper emphasizes the need for
             research to establish relationships between human static
             force capacities and the abilities to perform dynamic work
             at maximal and submaximal levels. Presently, there is
             little evidence that static force data accurately predicts
             dynamic performance.

CITATIONS: Seventy-six references.

METHODS: Male subjects, with high degree of physical fitness, from VIC's
Mine Rescue Service and laboratory workers in the United States
were employed in the study. The holding part of the study had
two experimental series. In the first series, 10 subjects held
weights for 2.5 minutes in three ways: 1) 20 kg in right hand,
2) 20 kg in the left hand, and 3) 20 kg in each hand at the same
time. An interval of 20 minutes was provided between conditions.
The weights were handed to the subjects to prevent any cardio-
vascular responses due to postural changes. Blood pressures
and heart rates were measured for 2 minutes before and during,
and for 5 minutes after weight holding. Blood pressures were
recorded by auscultation with a microphone stethoscope at
30 second intervals while heart rate was measured from a
continuously recording ECG, counted over a 30 second period.

In the second series of experiments the cardiovascular
responses of the subjects were compared when 40 kg were held
in the hands and on the shoulders. Ten subjects were examined
in the standing position on two occasions; on the first occa-
sion the subjects held 20 kg in each hand simultaneously, for
2.5 minutes. On the second occasion a well padded shoulder
harness weighing 40 kg was worn for 15 minutes. Heart rates
and blood pressures were recorded as in the first series.

To check and extend the results of previous experiments that
20 kg constituted a weight that quickly induced fatigue when
held by hand, whereas 40 kg could be supported on the back for
at least 15 minutes without fatigue, the cardiovascular res-
ponses produced by supporting a series of different weights
in these two ways were examined. First, the BP and HR of
eight standing subjects were measured on four occasions when
they held in their preferred hand, 5 kg for 5 minutes, 10 kg
for 5 minutes, 15 kg for 2.5 minutes, and 20 kg for 2.5 minutes.
In addition, measurements were made when they held 10 kg in
their left hand for 5 minutes and 10 kg in each hand for 5
minutes.

Cardiovascular events were also compared during actual stretcher
carrying by the conventional hand method with the responses when
the stretcher was supported by a shoulder harness. Ten men,
working in teams of two, were examined in two ways. On one
occasion each pair walked at 2 mph on the level, carrying by
hand a stretcher and subject (total weight 80 kg) to the point
of exhaustion. On the other occasion the same pair were examined
when the weights were supported by the shoulder harness. The
subjects walked again at 2 mph, but this time stopped after 15
minutes.

184

Lind & McNicol, 1968 (continued)

RESULTS: All 10 subjects studied were able to hold 20 kg in each hand,
            separately or together, for 2.5 minutes. During the three
            work periods, when the subjects held 20 kg in each hand, first
            separately and then together, large increases in systolic and
            diastolic blood pressures and heart rates occurred. There was
            a wide variation in the absolute values reached by individuals,
            but they all showed the same pattern of response. The increases
            of systolic and diastolic blood pressure were of the same order,
            so that the estimated mean blood pressure (diastolic plus 1/3
            pulse pressure) was correspondingly elevated. When the weight
            was held in the left hand, the increments of heart rate and
            blood pressure were somewhat greater than when the same weight
            was held in the right hand. Since all the subjects were right
            handed, it was assumed that the muscles of their right hand
            were stronger than their left hands. When the 20 kg weights
            were held in each hand simultaneously, the increments of mean
            blood pressure and heart rate were greater than when 20 kg were
            held in the right hand, but were very similar to those found
            when 20 kg were held in the left hand. This is in agreement
            with earlier findings that during two simultaneously sustained
            contractions, the cardiovascular responses were not additive
            but corresponded to the level of responses produced by the
            muscles which were contracting to the higher relative tension.
            The cardiovascular responses found when the subjects carried
            20 kg in each hand simultaneously were strikingly different
            from those which occurred when they held the same total load
            (40 kg) in a shoulder harness. The increase in the mean blood
            pressure and heart rate rose initially, and thereafter remained
            steady at their new levels for as long as the weight was held -
            15 minutes.
            Subjectively, the local effects on the muscles involved in
            the two types of weight bearing were also very different.
            Whereas the arm muscles involved were close to fatigue at 2.5
            minutes, the muscles involved in shoulder carriage had not
            fatigued after 15 minutes, and on two occasions when the test
            period was extended, there was no fatigue after 30 minutes.
            In order to establish some dividing line between what con-
            stituted a fatiguing and non-fatiguing load for each method
            of weight carriage, the responses of five subjects were then
            studied when they held different weights by hand and in the
            shoulder harness. The changes in HR and BP were measured
            in eight subjects who held 5 kg, 10 kg, 15 kg, and 20 kg in
            their right hands. On separate occasions, when the subjects
            held 5 kg and 10 kg, their BP and HR rose quickly but reached
            new steady state levels. The level of each steady state de-
            pended on the weight held and was independent of the duration.
            When the subjects held 20 kg, their BP and HR rose steadily
            and muscle fatigue occurred rapidly. The responses varied
            holding 15 kg. Thus, for six of the eight subjects, the
            weight which separated a non-fatiguing load from a fatiguing
            load for the arm was between 10 kg and 15 kg.

185

Lind & McNicol, 1968 (continued)

RESULTS: (continued)
             A similar pattern emerged on the eight subjects while they
         carried 40 kg and 120 kg in a shoulder harness. It was con-
         cluded that the critical weight was between 80 kg and 120 kg.
             For the carrying part of the study, the results for the two
         males carrying the stretcher (hand and shoulder harness) were
         strikingly different. The increase in BP and HR was much high-
         er when the stretcher was carried by hand and the subjects
         stopped because of fatigue, whereas the subjects were not fa-
         tigued after 15 minutes of carriage by the shoulder straps.

SUMMARY: Blood pressures and heart rates were measured when various
         weights were supported by hand and by a shoulder harness.
         The responses fell into the following two categories depending
         on the weight and the strength of the muscle groups: 1) fatiguing
         responses where blood pressures and heart rates rose progres-
         sively throughout, until at fatigue, the BP was very high and
         2) non-fatiguing responses whereafter an initial moderate rise,
         the BP and HR remained stationary.
             Hand carriage in excess of 10 kg and shoulder carriage in
         excess of 80 kg produced the fatiguing type of response.
             Stretcher carrying is an extreme example of the tasks where
         the above findings have any implications. In mining, stretchers
         may have to be carried by men for distances of a half mile or
         more underground before any other mode of transportation can be
         used.

CITATIONS: Twelve references.

METHODS: Biomechanical strength modeling involves the comparison of maximum voluntary torques to torques resulting from a lifting task. This comparison is made at each of the five major body articulations (ankle, knee, hips, shoulder, and elbow). Maximum voluntary torques are calculated from data gathered on carefully controlled and dimensioned task equipment. The resultant torques on each joint are made up of two components. First, the weight to be lifted creates a torque when displaced a known distance from the joint center. Second, the weights of the body links create torques around the articulations which also must be reacted to by the muscles involved. Also required as input to the program are maximum voluntary torque capabilities of the subject. The model generates force predictions on the basis of subject voluntary strength.

The ability of a muscle to produce a torque varies with the included angle of the joint across which it is pulling. Curves representing these variations are general population curves which are input to the biomechanical model. Also, subject test torques at specified angles are input to the program. The muscle torque producing capability at the angle of interest (determined by the current body position) is calculated as follows:

$$ST_\alpha = PT_\alpha \frac{ST_{\alpha 1}}{PT_{\alpha 1}}$$

where

ST_α = Subject torque at angle of interest.

PT = Population curve value at angle of interest.

$ST_{\alpha 1}$ = Subject test value at test angle.

$PT_{\alpha 1}$ = Population curve value at test angle.

α = Included articulation angle of interest.

$\alpha 1$ = Included articulation angle at test position.

Subject reactive torque capabilities are determined at all articulations by this method. The model then compares the resultant torques with the respective reactive strength. If the resultant torque exceeds the reactive capability at any articulation, that joint is said to be "critical" under the current loading.

187

Martin & Chaffin, 1972 (continued)

RESULTS: The three tasks evaluated for a subject applying force to a
             test object can be defined as: lifting, pushing, and pulling.
             Results for both males and females at the 50 percent and 95
             percent levels are considered; 95 percent level capabilities
             are lower than the corresponding 50 percent level capabilities.
             Many observations of general interest can be made from the
             results obtained.
             1. Lift capability in standing position decreases nearly
                linearly with horizontal displacement, regardless of verti-
                cal height.
             2. Lift capability is greatest when the hands are close to the
                knees.
             3. Lift capability near the body is lower when the load is
                waist-high as opposed to knee or shoulder-high due to poor
                mechanical advantage of the arms and back at waist level.
             4. Subjects in a seated position demonstrate constant lift
                capability at the lower vertical heights until the weight
                is displaced two feet horizontally from the joint.
             5. Pushing capability increases generally with an increase
                in horizontal displacement, with this relationship nearly
                linear in the upper vertical heights.
             6. Pulling as #5.
             7. Female lift capability at the 95 percent level is quite low.

SUMMARY: The branch of biomechanics considered in this model involves the
             study of human physical attributes during non-repetitive short-
             duration tasks; "short-duration" is considered to be less than
             4 seconds. Thus, the predictions involve musculoskeletal system
             limitations, not cardiovascular system limitations. The
             evaluation presented in no way applies to the endurance capa-
             bilities of men. The output predictions of the model described
             here are only useful when applied to infrequently occurring
             (less than once every 5 minutes), single-effort tasks. The
             model is also only effective for symmetric sagittal plane pre-
             dictions. It considers equal-extremity actions performed
             directly in front of the human operator.

CITATIONS: Twenty-one references.

STUDY: McConville, J.T. and Hertzberg, H.T.E. A study of one-handed
            lifting: Antioch College, Yellow Springs, Ohio and Aerospace
            Medical Research Laboratories, Wright-Patterson Air Force Base,
            Ohio, May 1966.

KEYWORDS: One handed lift, box size, psychophysical

METHODS: This study used 30 male volunteers, ranging in age from 18 to
            39 years, as subjects. Seventeen anthropometric dimensions
            for each subject were recorded. Each subject was asked to lift
            boxes of varying sizes (height remained constant, only width
            and length changed) using his right hand only with his palm
            and fingers up. The boxes were lifted from the floor to a
            table. The subjects had to do this by straightening their
            legs, pausing in the lift briefly after coming upright, and
            then making a biceps-flexion lift to the table top. Thirty
            pounds were put in the box initially. Each subject lifted
            this initial load and then additional weights were added to
            the box until each subject had achieved his maximum possible
            one-handed lifts. The next series of trials were run using
            different box sizes.

RESULTS: The test results were tabulated and graphed. The maximum
            weight of the box that subjects were able to lift varied
            linearly, but inversely, with the width of the box. From the
            data collected the maximum weight that 95% of the population
            would be able to lift was expressed by the linear equation:
            $Y = 60 - X$, where Y is the weight (lbs.) of the object to be
            lifted and X is the width (inches) of the object.

SUMMARY: The author stated that the primary objective of this investi-
            gation was to determine the optimum size and width of a con-
            tainer that the Air Force population can conveniently lift
            with one hand. He also concluded that the major result was
            the formula $Y = 60 - X$, by which the recommended upper limit for
            weight and width of a container could be found under ideal
            conditions.

CITATIONS: Nine references.

1.0

1.1

1.25

4.5
5.0
5.6
6.3

2.8

3.2

3.6

4.0

2.5

2.2

2.0

1.8

1.4

1.6
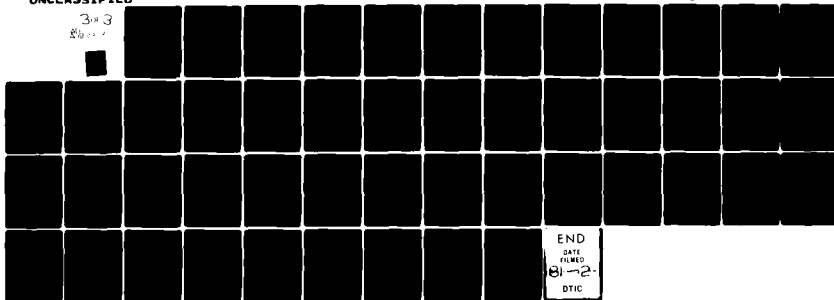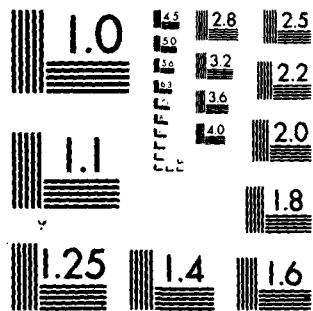
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

SUMMARY: This paper outlines the extant problems in Manual Materials
Handling Activities (MMHA), along with their etiology and
prevention. The following outline presents those areas
reviewed by the paper.

I. The problem of accidental deaths and injuries.
  A. Major classes of accidental deaths.
  B. The age and sex of accident fatalities.
  C. Trends in accidental death rates.
  D. The prevalence of nonfatal injuries.

II. Research on accidents.
  A. The problem of definition in accident research.
  B. Conceptual approaches in accident research.
    1. The epidemiological model.
    2. Systems safety analysis.

III Current trends in accident research and the development
  of countermeasures.
  A. The specific etiology of injury-abnormal exchanges of
     energy.
  B. Medical – engineering collaboration in the prevention
     of injury.
    1. Analysis of motor vehicle injuries.
    2. The "vehicles" of destructive energy in crashes.
    3. The forces involved in motor vehicle crashes.
    4. The determination of injury thresholds.

IV Applications of biotechnology to the control of injuries.
  A. Examples illustrating the point of view of biotech-
     nology.
  B. Contributions of anthropometry to occupational safety.
  C. Implications of biomechanical information for occupa-
     tional safety.
    1. Lifting objects varying in weight.
    2. Carrying objects in occupational tasks.

V Summary – the author states that one of the most important
   approaches to the prevention of injuries relates to the
   control of energy at the source, so that it will not impinge
   on the body. To control energy at the source, the physical
   stresses in the environment must not exceed the thresholds
   of human tolerance in potentially hazardous situations.

CITATIONS: Forty-two references.

STUDY: Minard, D., Goldsmith, R., Farrier, P. & Lambiotte, B.
           Physiological evaluation of industrial heat stress. American
           Industrial Hygiene Association Journal, 32(1), 17-28, 1971.

KEYWORDS: Heart rate, body temperature, heat stress

METHODS: Subjects were volunteers from the work force of the open hearth
           department of a large steel mill. Two series of subjects were
           used. Series A consisted of 19 men representing three job
           categories. Total heart beats were monitored separately during
           work, during waking hours off, and during sleep. Mean tempera-
           ture of the skin (t_s) of the anterior chest wall during each
           period was also monitored. Series B consisted of seven subjects
           in the open hearth department. The EKG and HR during standard
           5-minute exercise at 125 watts work output on a bicycle ergo-
           meter were recorded pre-shift and post-shift. Continuous re-
           cording of EKG during the shift was made. A measurement of
           total sweat rate was also made.

RESULTS: Results showed that men in series A expend 31 percent to 36 per-
           cent of maximum cardiocirculatory capacity on the job. HR on
           the job varied inversely with individual work capacity esti-
           mated from pre-shift performance on an ergometer. HR gradients
           to heat levels were nearly as great as to task levels in summer.
           In winter, HR gradient to heat was only 33 percent of that in
           summer, but HR responses to task were unchanged.

SUMMARY: Heart rate (HR) and body temperature (t_b) were studied in men
           on jobs in the open hearth department of a large steel mill.
           In 19 subjects on various jobs, mean HR for the shift was com-
           pared to mean HR off work and during sleep. Results showed that
           these men expend 31 percent to 36 percent of maximum cardio-
           circulatory capacity on the job. In 12 tests on five second
           helpers, continuous EKG records on magnetic tape revealed
           individual mean HR's for the shift ranged from 99 to 136/minute
           in summer and 97 to 111/minute in winter. HR on the job varied
           inversely with individual work capacity estimated from pre-shift
           performance on an ergometer. Performance decrement was observed
           for post-shift in two subjects with the lowest work capacity. HR
           responses, counted each 0.5 minutes of the shift, were analyzed
           by computer with task effort and heat exposure as independent
           variables. HR gradients to heat levels are nearly as great as
           to task levels in summer. In winter, HR gradient to heat was
           only 33 percent of that in summer, but HR responses to task
           were unchanged.

CITATIONS: Twenty-five references.

191

STUDY: Noro, L.   Medical aspects of weight carrying.   Industrial
                  Medical Surgery,   36(3), 192-195, 1967.

KEYWORDS: Preventive techniques, weight carrying, pathology, accidents,
                  back trouble, aspects of workers.

METHODS: Literature is reviewed with the thought in mind that the duty
                  of an occupational physiologist, biotechnologist or industrial
                  physician is to find the preventive means for back injuries by
                  keeping the work and working environment as healthy as possible
                  and by placing into jobs persons who are physically fit for the
                  tasks involved.

RESULTS: In answering the question "What should be the maximum permissible
                  weight carried by one worker from the health point of view?", it
                  is very difficult, biologically, to find any arithmetical
                  figures in kilos or pounds which could serve as a final norm to
                  limit every individual case. For instance, in addition to the
                  weight of the load, the individual working capacity varies
                  from man to man in the same country and even more between
                  various countries.
                       In trying to fix a maximum permissible weight, many other fac-
                  tors must be taken into consideration, such as duration of carry-
                  ing, technique, work breaks, and many environmental factors such
                  as temperature and humidity of air, etc. One must take into
                  consideration the fact that among the workers there are always
                  young and old, men and women, slender and thick, healthy and
                  sick, tall and short. Workers are not 100 percent healthy, and
                  this means that the working capacity differs very much from
                  person to person.
                       Carrying as a working process always includes lifting, carry-
                  ing, and lowering of the load. The health effects of this can
                  be acute (sprain of the muscles and the joints, aggravation of
                  circulatory and respiratory organs) or chronic (stress diseases).
                       Women and young workers need special attention with regard to
                  load carrying due to weak construction of vertebrae, bones, mus-
                  cles and circulation organs, lower oxygen uptake, etc. Training
                  however, can increase their strength and physical fitness.
                       From the pathological point of view, lifting is perhaps the
                  most important cause of acute accidents and lower back troubles.
                  The space between the lumbar V and the sacral I vertbrae is
                  especially a weak point in this respect.
                       A pre-employment screening procedure would be good for workers
                  about to get involved in lifting or carrying heavy loads. A check
                  for circulatory diseases should be made and the general health
                  of the worker should be determined.
                       Health education should be an important requirement and the
                  management should ensure that the workers are using correct
                  lifting and carrying techniques. Films, lectures etc., should
                  be used for this purpose.

                                          192

Noro, 1967 (continued)

SUMMARY: Noro reviews literature with the end result being that technolo-
             gists who deal directly with workers and occupational hazards should
             be more aware of preventive measures that can be used to protect
             the workers from accidents.
                 Industrial physicians should take an active part in health
             education. Modern ergonomics or biotechnology should be applied
             as far as possible in lifting and carrying. In particular,
             management should be trained to ensure that the workers are
             using correct lifting techniques. Another important point is
             to strengthen the muscles of the back by regular exercise. In
             educational work, lectures alone are not enough, and every
             worker should be given printed material on the right methods.
             Films should also be available and may be of help in this con-
             nection.

CITATIONS: Twenty-one references.

METHODS: It has been described by Asmussen, et al. (1965) that $W = 1.4 \cdot M - \frac{1}{2}$ body weight, in which $W =$ maximum weight of burden and $M =$ backward directed pull of the back muscles as measured at the height of the shoulders. In a state of equilibrium, the torque relative to a frontal axis through the lumbosacral joint will be: $(W \cdot \sin V) \cdot 1 - M \cdot 1 = 0$, where $V =$ the angle of body tilt, $1 =$ length of the spine from the shoulders to the lumbosacral joint. By solving for W, one gets: $W = M/\sin V \cdot$ M can be measured by having the subject pull maximally on a dynamometer; for practical purposes V is assumed to be $45°$; the maximum weight of the burden is $(W - .5 \times$ body weight).

To test the validity of this predictive formula, a series of experiments have been performed on 25 women and 21 men, ages 17 through 60 years, of various occupations, and weighing from 40-90 kg. The experiments will be discussed under two headings.
1.   Lifting from floor to an upright position, and
2.   lifting from a fixed shelf to a shelf placed at head height of the subject.

1. Lifting from floor to an upright position

A wooden box, measuring $30 \cdot 35 \cdot 26$ cm with handles placed 20 cm above the bottom at both sides, was loaded approximately with the predicted maximum weight. The subject, with a straight back, bent down by a flexion in the hip and knee joints and grasped the handles. By extending the legs and gradually straightening the back, the subject then lifted the burden from the floor until an upright position was attained. By adding or subtracting weights to the box, the maximum weight that could just be lifted in this way was found.

2. Lifting from a fixed shelf to a shelf placed at head height

A fixed shelf, 82 cm above ground level, and an adjustable higher shelf were used. With the subject standing erect the adjustable shelf was placed over the fixed shelf at the height of the tip of the nose. A small sack with sides measuring $50 \cdot 35$ cm^2 was loaded with the weight predicted from the formula: $\frac{1}{2}$ (sum of the right and left arm push). The subject grasped the sack and lifted it up to the upper shelf. By adding or subtracting weights to the sack, the maximum weight the subject could just push up on the shelf was found.

RESULTS: 1. Lifting from floor to an upright position

The data collected from the experiment has been plotted against (i) body weight, (ii) the strength of back muscles, and (iii) the maximum load as predicted from the formula described in the methods above. It was found that there is no clear correlation between the maximum load that can be lifted and the body weight of the subject. The equation for the regression

194

Poulsen, 1970 (continued)

RESULTS: (continued)

line for women is $y = .46x + 15.2$ kg and for men, $y = .14x +$
76.9 kg in which y is maximum load, and x is body weight, both
in kg. The correlation factor, r, is low, for women r = .28
and for men even lower, r = .06. The relation between the
maximum weight that could be lifted and the back muscle strength
is also computed; the equation for the regression line is:
for women $y = .96x - 7.7$ kg, and for men $y = 1.0x + .42$ kg.
The correlation is quite high (women: r = .78 and men: 4 = .72).
Men are lifting 8 to 10 kg more than women at identical back
muscle strength. Also the relation between the maximum load
lifted and the load that was predicted from the theoretical
formula is calculated. Here the correlation is quite high for
both women (r = .73) and men (r = .76), the men being able to
lift heavier burdens than women at identical predicted lifts.
The conclusion to be drawn here must be that the maximum weight
a person can lift can neither be fixed as a standard load, nor
defined as a load related to the person's body weight. A load
equal to the actual strength of the back muscle seems to give
realistic values, while the determination from the predictive
formula where also the weight of head, arms, and trunk of the
subject is included does not seem to give a better result than
predicted from the back muscle strength alone.

2. <u>Lifting from a fixed shelf to a shelf placed
at head height</u>

The maximum load the subject could lift in this way was
plotted against the load predicted from the formula. Regres-
sion lines for men and for women separately have been calculated
and the correlation factor, r, has been determined. It is con-
cluded that men are able to lift more than women and that the
regression line for men is placed above that for women. The
equations for the regression lines are: for men, $y = .91x + 8.72$
kg, and for women, $y = .72x + 8.27$ kg. The correlation factor
r is .66 for men and .62 for women. The maximum load that
could be lifted to head height was also plotted against strength
of hand grip (average of right and left). The correlation was
also fairly high, corresponding to the fact that strength of
hand grip correlates highly with strength of arm push.

SUMMARY: Theoretical predictions of how heavy a burden a person can lift
(A) from floor to table height and (B) from a fixed shelf to a
shelf placed at head height have been tested in practice.
When lifting loads from the floor to table height the strength
of the back muscles often will be the limiting factor. When lift-
ing a load from table height to a shelf placed at head height,
it is the strength of the arm push that will be the limiting
factor.

The prediction formula for (A) is maximum load = (maximum
isometric back muscle strength) x 1.4 - .5 x body weight.
After experiments with 50 men and women it was found that the

195

Poulsen, 1970 (continued)

SUMMARY: (continued)
             correlation between maximum load was highly correlated to both
             the predicted maximum load to back strength (r = .7). For (B)
             the predictive formula was: maximum load = 1/2 * (sum of right
             and left maximum isometric arm push). After experiments, it
             was found that the correlation factor r between prediction
             and actual maximum load was .6. For A the regression lines for
             maximum load and back muscle strength, and maximum load and
             predicted maximum load, were different for men and women, men
             being able to lift heavier burdens than women with the same
             measured back muscle strength. For B also the regression lines
             for men and women were different with men lifting more than
             women with the same measured muscle strength.

CITATIONS: Thirteen references.

STUDY: Ramsey, J.E. & Purswell, J.L. The correlation of mechanical and physiological measures of work movement of the upper limb. AIIE Transactions, 3(2), 97-103, 1971.

KEYWORDS: Mechanical variables, physiological variables, heart rate (HR)

METHODS: The correlation of mechanical and physiological variables reported proceeded from two independent studies. Some subjects were used in a joint experiment. The work task consisted of a seated operator performing a typical motion pattern while carrying a load in his hand. A dead weight shaped to fit the hand with the fingers encircling it was between two targets which defined the length and plane of motion. The work task was paced at a rate of 50 cycles per minute and lasted for 4 minutes.

The seven mechanical measures of work considered were velocity and acceleration of movement, total mechanical energy, force, torque, linear impulse, and angular pulse. The three physiological measures were pulmonary ventilation rate, pulse rate, and oxygen consumption.

A Max Plank gas meter was used to measure the pulmonary ventilation volume. The oxygen analysis was performed using a Beckman E2 oxygen analyzer. Surface electrodes, amplifier, and counter were used to record the heart rate of the subject. An exoskeletal kinematometer was developed and used to continuously monitor the arm motion. The angle of abduction for the upper arm was measured with respect to the midsagittal plane of the body, using the shoulder as a reference point.

RESULTS: Analysis of variance was used and it was found that ventilation rate was highly significant to the variables of weight carried, angle of abduction, distance of reach, and type of work. Heart rate was also sensitive to those variables but not as sensitive as the ventilation rate. Oxygen consumption was sensitive only to distance of reach.

Analysis of variance also indicated that the variables of weight, distance and angle of abduction all had highly significant effects on the mechanical measures of energy, torque and angular impulse.

Increase in ventilation rate/BSA has the highest correlation among the three physiological criteria for every mechanical measure tested and it varied from .531 for shoulder angular impulse to .353 for average shoulder force. Conversely, increase in oxygen consumption/BSA consistently showed the lowest correlation to the mechanical criteria.

SUMMARY: An experimental approach to determine the correlation of some mechanical measures of work with some physiological measures of work, for a task performed by the upper limb, was undertaken. The seven mechanical measures of work were velocity and acceleration of movement, total mechanical energy, force, torque, linear impulse, and angular impulse. The three physiological measures were pulmonary ventilation rate, pulse rate, and

197

Ramsey & Purswell, 1971 (continued)

SUMMARY: (continued)
oxygen consumption. Pulmonary ventilation rate was found to
correlate best with all the mechanical measures, with shoulder
angular impulse and average shoulder torque having the highest
correlation of the mechanical measures.
   This study is an important contribution towards quantify-
ing human capability and measuring human effort for the dynamic
work task.

CITATIONS: Twenty-five references.

STUDY: Ronnholm, H. Physiological studies in the optimum rhythm of
              lifting work. Ergonomics, 5(1), 51-52, 1962.

KEYWORDS: Lifting, rhythmic periods, heart rate, energy consumption, blood
              lactic acid, efficiency.

METHODS: The influence of arranging the work into rhythmic periods was
              studied by means of comparative experiments. A light lifting
              work performed with the right hand was chosen for the experi-
              ment. Two healthy sportsmen were used as subjects. Energy
              consumption, heart rate, and blood lactic acid were determined.
              A typical example of the task is: a weight of 5 kg was put on
              a table with a height of 63 cm and the work consisted of lifting
              the weight to another table with a height of 75 cm and lowering
              it again to the table with a height of 63 cm. The lifting was
              performed either with regular interruptions (20 lifts/minute)
              or with a continuous rhythm (10 lifts in a series or free rate,
              then 30 seconds rest, 10 lifts, 30 seconds rest and so on)
              during 10 minutes.
                After this experiment, trials were made in order to find out
              the optimum conditions under which least energy was required
              for a standard work output. The weight, distance and rate of
              lift were varied.
                In order to find the ratio of working time to resting time,
              the performance was filmed. When lifting rhythmically at a
              rate of 10 times/minute (12 cm, 5 kg) the time ratio was 1:4;
              for 20 and 30 times/minute the ratio was 1:1.2 and 1:0.8 re-
              spectively.
                When lifting at the optimum rate (30 times/minute rhythmically),
              the subject used on an average 0.56 seconds to lift the weight,
              kept it in that position for .25 seconds, lowered the weight in
              .5 seconds and kept it in that position for .19 seconds before
              the next cycle started.

RESULTS: The results showed that lifting performed with a certain rhythm
              was much more economical. When the work was performed with re-
              gular interruptions at the rate of 20 times/minute, the energy
              expenditure was 2.38 Kcal/minute. With a continuous rhythm,
              the energy expenditure was only 1.97 kcal/minute.
                In the second case the same work was done with a higher mechan-
              ical efficiency. The optimum efficiency was reached at a rate
              of about 30 lifts/minute. The energy expenditures were 2.4 and
              2.04 kcal/minute for rhythmic and non-rhythmic work respectively.
                After these, when the distance of lift and the weight lifted
              were changed, it was observed that with doubling the distance,
              energy consumption was tripled. The optimum distance was found
              to be around 12 cm. Optimum load was found to be about 5 kg.
              Blood lactic acid ranged from 18 to 63 mg percent.
                It was observed that to lift 5 kg 20 times/minute is more
              economical than to lift 10 kg 10 times/minute, either with
              regular interruptions or rhythmically. It was more economical
              to lift a load 5 kg 40 times/minute than to lift 10 kg 20 times/
              minute when performed rhythmically. It was more economical to
              lift a load of 5 kg over a distance of 24 cm 20 times/minute
              than to lift it over a distance of 12 cm 40 times/minute.

Ronnholm, 1962 (continued)

SUMMARY: When light lifting work is to be performed, it is possible to
            do the lifting in two ways: either with regular interruptions
            or arranging the lifts into work periods with distinct intervals.
              The essential finding in this study is that physiological
            considerations of the problem of lifting contribute to ergonomics
            and may be applied to the solution of practical working situations.
            When light lifting work is performed rhythmically, efficiency and
            output may be increased and the work load may be reduced.

CITATIONS: *No references.*

STUDY: Ronnholm, H., Darvonen, M.J. & Lapinleimu, V.O. Mechanical
efficiency of rhythmic and paced work of lifting. Journal of
Applied Physiology, 17(5), 768-770, 1962.

KEYWORDS: Lifting, rhythm, pace, energy expenditure, mechanical effi-
ciency

METHODS: The work consisted of relatively light lifting with the right
hand. An example of the experiment: a weight of 5 kg was put
on a table at the height of 63 cm; the subject had to lift
it onto a table 75 cm high and to lower it again to the 63 cm
table. The lifting was performed at a rate of 20 lifts/min.
In rhythmic work, the subject made 10 lifts at a rate chosen
by himself, every 30 sec., resting during the intervals.

In further experiments, the weight, the vertical distance
lifted, and the rate of lifting were varied. In all experi-
ments with rhythmic work, however, the work has started every
30 sec. Work at different rates was filmed at the rate of 16
frames/sec., and the time spent for the different movements
was studied from the film.

The ventilation was measured with the aid of Miller-Franz
apparatus during each 10 minute experiment and in some cases
also 5 minutes during recovery. Oxygen in the expired air
was determined with Beckman oxygen analyzer, model C. The
heart rate was counted by feeling the radial pulse during work.
In some experiments, blood lactic acid was determined.

RESULTS: A time study was made from the films. When the rate was speeded
up from 10 to 30 lifts/min, the actual lifting became only a
little faster, mostly cutting the pauses shorter. At each
frequency both the lifting cycles and the pauses were shorter
in rhythmic than in paced work.

In paced work at 20 lifts/min. the total energy expenditure
was 2.38 kcal/min. In rhythmic work the energy expenditure
was markedly less, only 1.97 kcal/min. These values include
the energy required for standing upright (1.58 kcal/min.).
One of the subjects attained the optimum efficiency at the
rate of 30 lifts/min. while the other attained it at the rate
of 20 lifts/min. The mechanical efficiency of rhythmic work
was much greater than that of paced work. It was observed that
at a high rate of lifting, as the rhythmic work approaches
the character of paced lifting, the difference in the mechani-
cal efficiency of the two types of work also tends to dis-
appear. When the vertical distance is increased, the differ-
ence in mechanical efficiency between rhythmic and paced work
tends to disappear. The difference was greatest at about 12 cm.
The mechanical efficiency was much higher in rhythmic than in
paced work at 5 kg load. The difference disappeared with loads
of 2 kg and 10 kg.

For all tasks, the heart rate was slower in rhythmic than
in paced work. Lactic acid determinations ranged from 18 to
63 mg/100 ml.

201

Ronnholm, et al., 1962 (continued)

SUMMARY: Weights of from 2 to 10 kg. were lifted to levels 5 to 44 cm higher and back again at the rate of 10 to 40 cycles/minute. The optimum rate in terms of energy efficiency was 20 to 30 lifts/minute. With this rate, a load of 5 kg, and a lift of 12 cm, about half as much energy was expended when the subjects were permitted rapid, rhythmic completion of lifting and a compensatory pause during each 30 sec. of scheduled work as when the same amount of work was performed at equal intervals throughout. The difference between rhythmic and paced work diminished to zero as the number of lifts were increased to 40/minute. At loads of 2 and 10 kg and also over the distance of 5 and 44 cm, paced and rhythmic work required equal energy expenditure. The heart rate was also slower in rhythmic than in paced work. The difference was largest (16/minute) when lifting 5 kg over 12 cm at the rate of 30 lifts/minute.

The introduction of an element of rhythm thus resulted in a saving of physiological effort under strictly defined conditions. This study attempts to determine an optimum speed at which the mechanical efficiency of the work is highest.

CITATIONS: Five references.

METHODS: Static Strength Test: Following adjustments of the handle of a calibrated Stoelting dynamometer for individual differences in size of hand grip, each subject, who was seated, completed five maximal contractions with 2 minute rest intervals between each contraction.

Isometric Endurance Test: The subject was encouraged to sustain statically a maximum isometric contraction for two minutes, immediately following which he relaxed his grip for approximately a quarter second and completed one rapid maximal contraction.

Isotonic Endurance Test: Using the same body and limb position, equipment, and recording device that was employed in the static strength test, the subject completed a 6 minute alternating maximal grip-rest-grip-rest cycle of exercise. During the 6 minute test the subject alternated work and rest cycles (each 3 minutes in length).

RESULTS: It was found that an individual's static strength training program is a poor prediction of his post-training increments in strength performance, i.e., the correlation between static strength and post-training increment in strength was found to be only .169. Similarly in the present study static strength did not discriminate among individuals in regard to their potential in work performance as witnessed by the low correlations between strength and pre- and post-training isometric endurance viz r's = .270 and .408, and pre- and post-training isotonic endurance .374 and .303. Also, there is no radical comparative disagreement in results in reference to the prediction of work performance from individual differences in strength, i.e., correlations between strength increment and pre- and post-isometric and isotonic endurance ranged from .110 to .492. The inter- and intra-relationships between individual's isometric and isotonic "endurances" are predominantly low with non-significant correlations ranging from .242 to .338. However, although there was little relationship between pre-isotonic and isometric endurance (r = .242), pre-isotonic endurance was found to be a significant predictor of post-isotonic and initial isometric work capacity (r's = .741 and .743).

Therefore, it is quite apparent as a result of the wide scatter of correlations, one cannot predict from the strength measure how individuals will perform endurance activities.

Smith & Edwards, 1968 (continued)

SUMMARY: The object of the study was to determine the pre- and post-training changes upon the interrelationships between strength, isometric endurance, and isotonic endurance. A controversial research topic is the current problem concerning the relationship of individual differences in strength as a predictor of muscular endurance. Also in question are individual differences in static strength performance as a reliable predictor of work capacity prior to and following a significant increase in strength.

CITATIONS: Twelve references.

STUDY: Snook, S.H. The effects of age and physique on continuous work
              capacity. Human Factors, 13(5), 467-679, 1971.

KEYWORDS: Work capacity, age, physique, lifting, lowering, pulling, push-
              ing, carrying, walking, heart rate

METHODS: The basic tasks of lifting, lowering, pushing, pulling, carry-
              ing and walking were varied according to height distance and
              rate of work, resulting in a total of 54 separate tasks. The
              lifting and lowering heights correspond to the muscles which
              actually do the work, whereas the pushing and pulling height
              approximates handle heights commonly found in industrial
              situations. All tasks, except walking, were performed at high,
              medium, and low rates of work which were determined empirically
              during pilot studies. Heart-rate was chosen as a dependent
              variable. Telemetry equipment was used for this purpose and
              measurements of heart-rate were recorded only during high and
              intermediate rates of work.   Force was another dependent varia-
              ble for all tasks, except walking, and was adjusted by varying
              the weight of the object being handled. Rate was the dependent
              variable for the walking task.
                 Twenty-eight subjects, divided into two age groups, were
              required to handle an industrial tote box 13.5 x 19 x 5.5 in.
              with two 7 x 1-5/8 in. handles, and varied the weight of the
              box by adding or subtracting loose lead shot. Pushing, pulling,
              and walking were simulated on a specially constructed treadmill.
              The treadmill was powered electrically during walking and manual-
              ly, by the subject, during pushing and pulling. Strain gauges
              measured the force of pull and push. Forty-one anthropometric
              measurements were made of each subject at the beginning and at
              the end of the experiment. These were used to compute ecto-
              morphy, endomorphy, mesomorphy, density, body type, specific
              gravity, and for estimates of lean body mass. Subjects were
              instructed to adjust their work load to a comfortable level
              (very light or very heavy) and starting forces were randomly
              used. The adjustments for the two cases were averaged. Each
              task was performed for about 40 minutes in a controlled
              environment.

RESULTS: All force measurements for lifting, lowering, pushing, pulling,
              and carrying tasks were subjected to a three-factor analysis of
              variance (age by task by rate). No significant force differences
              were found between the two age groups.
                 The work-rate measurement applied only to the walking task.
              All walking-rate measurements were subjected to a two-factor
              analysis of variance - age by replication. No significant
              work-rate differences were found among the age groups or repli-
              cations. All heart-rate measurements for lifting, lowering,
              pushing, and carrying tasks were subjected to a three-factor
              analysis of variance (age by task by rate).
                 No significant heart rate differences were found between the
              two age groups. Significant differences were found among tasks,
              rates, and task by rate interaction. Heart-rate measurements

Snook, 1971 (continued)

RESULTS: (continued)
            for walking were subjected to a two-factor analysis of variance
            (age by replication). No significant heart-rate differences
            were found among the age groups or replications.

SUMMARY: The following hypotheses were investigated: 1) continuous work
            capacity does not decrease with increasing age, and 2) physique
            has a greater effect on continuous work capacity during slower,
            heavier tasks than during faster, lighter tasks. Twenty-eight
            male subjects, 14 between 25 and 35 years of age, and 14 between
            45 and 60 year of age, performed 54 manual handling tasks for
            a duration of 40 minutes. Three lifting, three lowering, four
            pushing, one pulling, and six carrying tasks were performed at
            three different rates of work. Three replications of a walking
            task were also performed. The continuous work capacity of each
            subject for each task was measured by a psychophysical technique
            which required subjects to adjust their work loads to the maxi-
            mum they could perform without feeling uncomfortable. Heart
            rate was monitored continuously during task performance. The
            age hypothesis was tested by subjecting both work load and
            heart rate data to analysis of variance. The physique hypo-
            thesis was tested by correlating work load data with each of
            the 41 anthropometric measurements obtained from each subject.
            The results supported the age hypothesis. The physique hypo-
            thesis, however, was supported only by the results of the
            younger group of subjects.

CITATIONS: Thirty-seven references.

METHODS: This paper discusses the prevention of low back injuries by designing the job to fit the worker. The author describes seven studies, six of which used psychophysical methodology. In the first study, heart rate and oxygen consumption were measured for 30 male industrial workers selected from three age groups. They performed different lifting tasks which varied in height, frequency, and object weight. The classification of lifting height used in this study was based upon the muscles that actually performed the lift. The second study was concerned with the maximum weight of lift and psychophysical methodology was used. The third study investigated lifting frequency and also used a psychophysical methodology. The fourth study investigated other types of manual handling tasks in addition to lifting, such as lowering, pushing, pulling and carrying. Using a psychophysical approach. The fifth study was the same as the fourth except it used all female workers so that the differences in sex could be investigated. The sixth study had to do with the effects of heat stress on manual handling tasks. The seventh study expanded and refined the manual handling data base by also looking at variables such as object length, object width, lifting distance, pushing height, and pulling height. In addition, questionnaires were sent to the Loss Prevention representatives of the Liberty Mutual Insurance Company to obtain data on tasks producing low back injury.

RESULTS: The author stated that in view of the differences in strength and endurance of all the people used, a good way to evaluate a manual handling task is in terms of the population that can be expected to perform the task without overexertion or excessive fatigue. For example, 18 kg. is the maximum acceptable weight for 75 percent of the male industrial workers lifting a large object (75 cm. width) through a 76 cm. distance from the floor to knuckle height once every minute (all the data is given in tabular form). Results from the questionnaires revealed that about one-quarter of the jobs (where the workers have worker's compensation with this company) involve manual handling tasks that are acceptable to less than 75% of the workers, and one-half of the low back injuries were associated with these jobs. No significant reduction in low back injuries was found in employers who used medical histories, medical examinations, or low back x-rays to select the worker for the job or for the employers who trained their workers to lift properly.

Snook, 1978 (continued)

SUMMARY: This paper reviews seven studies which were done pre-
                viously. It explains how the experiments were done and
                tabulates all the data from the experiments. The studies
                investigated lifting, lowering, pushing, pulling, carrying
                and walking, and had the following variables: height, dis-
                tance, and frequency of task; size and weight of the object;
                differences in worker sex, age, and physique; and the effects
                of heat stress. Six of the seven studies used a psychophysi-
                cal methodology. In addition, the effectiveness of the
                studies was investigated by analyzing randomly selected back
                injuries. The author then concluded that the proper design
                of manual handling tasks can reduce up to one-third of indus-
                trial back injuries, and, therefore, job design appears to
                be significantly more effective than selecting the worker to
                fit the job, or training the worker to lift properly.

CITATIONS: 42 references.

METHODS: A literature search was conducted to determine what is currently
known about low back pain in industry.

RESULTS: Low back pain is characterized by intermittency, but there is no
real agreement as to its cause. The six major theories that
have been offered as the cause of lower back pain are: sciatic
nerve theory, sacroiliac joint theory, psychoneurosis theory,
disc theory, muscle spasm theory, and facet joint theory. There
have been conflicting studies on lower back pain as related to
age, experience, seasonal variations, body height, and sex. It
seems that no one really knows the cause of lower back pain
or if there is a certain group of people it affects. Since the
cause of lower back pain is not known, it is very difficult to
prevent it, but attempts have been made through selection,
instructions, job design, and physical fitness. There is also
disagreement about the usefulness of low back x-rays for job
selection in pre-employment programs and whether or not there is
a correct, safe way to lift. Job design is another area where
attempts are being made to reduce the number of lower back pain
injuries. However, there is disagreement in what kind of jobs
produce back injury and even when back injury occurs. One thing
that is agreed upon by the references the authors used is that
physical fitness is important in preventing lower back pain.

SUMMARY: The author's conclusions are that, as indicated by his literature
search, the problems of low back pain are far from being solved
and that they may never be solved completely. He also seemed
to agree with Rowe (J. Occup. Med 11(4): 161-169, 1969) that it
appears impossible to prevent backache, but that it may be pos-
sible to reduce low back disability. The most promising method
in preventing the backache or reducing the disability appeared
to be physical fitness, followed by job design, selection, and
instruction; in decreasing order.

CITATIONS: Thirty-seven references.

KEYWORDS: Maximum acceptable weight of lift, females, physiological, work
            rate

METHODS: The six basic manual handling tasks were lifting, lowering,
            pushing, pulling, carrying, and walking. Sixteen housewives
            and 15 industrial workers were used as subjects. Independent
            variables were: height of lift, tote box weight, frequency of
            lift. Dependent variables were: force (except for walking),
            rate (for walking), heart rate. All tasks except walking were
            performed at fast, moderate, and slow rates of work.

RESULTS: Comparison of the results with earlier studies shows that the
            average weight handled by industrial man was significantly
            greater than the average weight handled by industrial women –
            which in turn was significantly greater than the average weight
            handled by housewives. The sex differences in object weight
            were greater for the lifting, lowering, and carrying tasks
            than they were for the pushing, pulling, and walking tasks.
            Sex differences in object weight were also greater at low rates
            of work than at high rates of work; although women handled
            significantly less weight than men, they expressed similar or
            significantly higher heart rates.

SUMMARY: An ergonomic study was designed and conducted to determine maxi-
            mum weights and work loads acceptable to female workers. The
            results are used to predict the maximum weights and work loads
            that are acceptable to various percentages of the female popu-
            lation. The purpose of this study was thus to determine
            whether the sex differences demonstrated with traditional
            laboratory tests would also occur with actual manual handling
            tasks used in industry.

CITATIONS: Fifteen references.

METHODS: Seven human and task variables are considered in the study.
These are: sex, age, training, physical fitness, size of the
object to be lifted, height from which and to which the object
is lifted, and frequency of lift. None of the previous six
studies investigated or held constant all seven of the variables
identified above.

Nine male subjects, between 25 and 27 years, were instructed
to adjust the weight of the tote box until they felt that it
was the maximum amount they could lift comfortably without
straining themselves once every 15 minutes. Subjects performed
push-up, pull-up, and deep-knee bend exercises for one week
prior to their participation. Eighteen 50-minute, thirteen 12-
minute, three 15-minute, and three 30-minute sessions of repeated
lifting were performed by each subject before any measurements
were recorded for analysis. The object lifted was a tote box,
13-1/2 x 19 x 5-1/2 inches with two 7 x 1-5/8 inches handles.
The subject varied the weight of the box by adding or removing
loose lead shot with a small scoop. The box weighed 10 lbs.
and contained a lalse bottom which could hold a maximum of 40
lbs. of lead shot. Weight of the "empty" box was varied between
10, 20, and 30 lbs.

Each subject made a total of 18 judgements; six for the
floor level to knuckle height lift, six for the knuckle to
shoulder height lift, and six for the shoulder to arm reach
height. For one-half of the judgements the initial total
weight of the box was 30 lbs.; for the other half 100 lbs. was
the initial weight.

Subjects made only one judgement per lifting height in a
single day.

RESULTS: The median weight for the six trials per lifting height was
obtained for each subject and the mean and standard deviations
were used to get the values of 90 percent, 75 percent, 25 per-
cent, and 10 percent of population. The following observations
were made:
1.   With only one exception, standard deviations are considerably
    smaller than in the two Air Force studies.
2.   There is a small difference between the three lifting
    heights when compared with previous studies.
3.   Results for the floor to knuckle height lift are somewhat
    less than for equivalent lifts in other studies.
4.   Results for the knuckle to shoulder height lift are in
    general agreement with equivalent lifts of other studies.
5.   Results for shoulder to reach height are somewhat greater
    than for equivalent lifts in other studies.

Snook & Irvine, 1967 (continued)

SUMMARY: It was concluded that 50 lbs. is the maximum weight of a compact
            object that should be lifted by unselected, adult male workers.
            The maximum amount of weight that an individual can be expected
            to lift comfortably and without strain is discussed. Six
            previous studies have been reviewed. The approach used in two
            Air Force experiments is identified as a variation of the
            psychophysical method of magnitude production. An improved ex-
            perimental design is described which includes the following
            advantages: 1) the control of additional variables not consid-
            ered in previous studies; 2) experimental controls and statis-
            tical procedures found necessary for use in psychophysical
            experiments; 3) instructions and tasks which are more applicable
            to industrial situations; and 4) subjects who are experienced
            industrial workers, older, and better conditioned to the lift-
            task.
              The study attempts to find a safe weight to protect individuals
            against injuries due to lifting and is useful in developing
            recommendations for maximum permissible safe weights.

CITATIONS: Twelve references.

212

METHODS: Of the numerous psychophysical methods designed for determining
           thresholds, a combination of the methods of adjustment and
           tracking was chosen as the most practical for long term, con-
           tinuous tasks.   Eight male subjects were required to lift an
           industrial tote box (19 inches long, 13.5 inches wide, and 5.5
           inches deep) repeatedly through a 20 inch vertical distance.
           A device was designed to lower the tote box automatically after
           each lift.

           There were two independent variables: tote box weight and
           height of lift.   The empty tote box weighed 20 lbs.   During
           one-half of the trials, the tote box weighed 35 lbs., and 50
           lbs. during the remaining half.   Three levels of height were
           used: floor to knuckle, knuckle to shoulder, and shoulder to
           functional arm reach.   Within each height level, the tote box
           was lifted through the standard 20 inch vertical distance.   The
           subject was paced by a repeating timer which activated a com-
           bination light and buzzer.   Control of the timer was given to
           the subject so that he could adjust the frequency of lift
           according to his feelings of fatigue.   The subject was instructed
           to imagine that he was working on a piece of work, getting paid
           for the number of lifts, but working a normal 8-hour shift that
           allows him to go home without feeling bushed.

           The initial frequency was randomly varied (3, 4, 5 or 6 seconds
           between lifts).   These values were chosen because they cannot be
           maintained for any length of time and consequently, subjects
           had to decrease the frequency of lift in order to follow the
           instructions correctly.   Each subject performed for test sessions
           of 4 hours each.   Five minute periods of repeated lifting were
           performed during the first session; 12 minute periods during the
           second session; 15 minute periods during the third session;
           each subject performed three 1-hour periods of repeated lift-
           ing, separated by a 15 minute rest period.

RESULTS: During the early minutes of the test session, subjects over-
           estimated the frequency of lift and had to slow down.   In 90
           percent of the tests during the last four days subjects made
           no further adjustments in lifting frequency after 40 minutes
           of the test had elapsed.   In the remaining 10 percent of the
           tests, small adjustments, if any, were made.

           To permit direct comparison between the 35 lb. and 50 lb.
           weights of lift, the frequencies were converted into foot-
           pounds per minute.   There were significant differences among
           the three heights and the two weights.   All three heights of
           lift were significantly different from each other.   Replica-
           tions were not significantly different, however.

213

Snook & Irvine, 1968 (continued)

SUMMARY: This study utilized a psychophysical approach to determine
             maximum frequencies of lift acceptable to male industrial
             workers. Eight subjects were required to lift continuously
             either a 35 lb. or a 50 lb. tote box through a 20 in. dis-
             tance at each of three different heights. The lifting task
             was paced by a repeating timer which the subject controlled
             according to his subjective feelings of fatigue. Visual cues
             were minimized as much as possible. Non-significant dif-
             ferences among three replications of the experiment lend
             strong support for the psychophysical methodology. Negative
             correlations between selected frequency of lift and subject
             height and weight are very similar to those reported by other
             investigators.
                This study supplements an earlier attempt by the authors to
             define the maximum frequency of lift that 90 percent of the
             healthy male industrial workers can perform without showing
             signs of excessive fatigue.

CITATIONS: Sixteen references.

METHODS: The study has two parts: 1) laboratory study and 2) field
study.

Laboratory Study:

Of the numerous psychophysical methods designed for determining
thresholds, a combination of the methods of adjustment and track-
ing was chosen as the most practical for long term continuous
tasks. Subjects were required to lift an industrial tote box
(19x13.5x5.5 in.) repeatedly through a 20 in. vertical distance.
Tote box weight and height of lift were two independent vari-
ables. The tote box weighed 35 lbs. during the first half
trials and 50 lbs. during the remaining half. Three height
levels were used: floor to knuckle, knuckle to shoulder, and
shoulder to functional arm reach. The subject was paced by
a repeating timer which activated a combination light and
buzzer. Control of the time was given to the subject so that
he could choose the frequency according to his sensation of
fatigue. The initial frequency was randomly varied (3.4, 5 or
6 seconds between lifts) and the subject was asked to lift on
a piece rate system for an 8 hour shift such that he can go
home without becoming tired.

The experiment was replicated three times for a total of 18
tests. Nine males performed as subjects. Each subject per-
formed 10 test sessions of 4 hours each, one test session
every other day. Five minute periods of repeated lifting were
performed during the first session, 12 minute periods during
the second session, 15 minute periods during the third session,
and 30 minute periods during the fourth session. During the
first four sessions, subjects were instructed in the correct
methods of lifting. During the remaining six sessions each
subject performed three 1 hour periods of repeated lifting,
separated by 15 minute rest intervals.

A continuous recording of work heart rate was obtained from
the subject's EKG signal and was telemetered by a small FM
transmitter. The final frequency of lift selected by each
subject was also recorded.

Field Study:

During the field study, 12 workers from a shoe factory partici-
pated. Subject ages ranged from 22 to 37. The task consists
of placing a shoe upper on a shoe last, securing it by pulling
the strings of the upper over pins on the last, and placing
the last into a mold where the sole is attached. Eleven of
the 12 workers operated six machines and the twelfth worker
operated only four machines but at a faster pace.

Heart rate was recorded for each worker, while he was per-
forming the string lashing task.

215

Snook & Irvine, 1969 (continued)

RESULTS: Laboratory Study:

1. There were no significant heart rate differences among the three replications.
2. There were no significant heart rate differences among the two weights of lift (35 lbs. and 50 lbs.).
3. There were significant heart rate differences among the three heights of lift. Floor to knuckle height lift was significantly different from the other two, but the other two were not significantly different from each other.

Field Study:

The mean heart rate for 12 workers was 100 beats/minute (while performing the task). There were no significant heart rate differences between the field and laboratory results.

The heart rate, as a fatigue criterion, has shown consistency in both the laboratory and field studies, and this lends strong support for the use of psychophysical methodology in future studies of fatigue criteria.

SUMMARY: A laboratory experiment and a field study were conducted using psychophysical methods for determining fatigue criteria. Heart rate was measured during these studies as an indication of the physiological level of functioning and was compared with fatigue criteria suggested by other investigators. The consistency of the results in the field study and three replications of the laboratory study demonstrated the reliability of the psychophysical and methodology.

Oxygen consumption criteria--There remains some doubt as to whether maximum continuous work capacity can be expressed as a percentage of maximum oxygen uptake.

Energy Expenditure Criteria--It is quite adequate for leg tasks, but slightly high for arm tasks (Lehmann's criterion).

CITATIONS: Thirty-five references.

STUDY: Snook, S.H., Irvine, C.H. & Bass, S.F. Maximum weights and work loads acceptable to male industrial workers. American Industrial Hygiene Association Journal, 31(5), 579-586, 1970.

KEYWORDS: Lifting, lowering, pushing, pulling, carrying, walking, psycho-physical methodology, work load

METHODS: The six basic manual materials handling tasks of lifting, lowering, pushing, pulling, carrying and walking were varied according to height, distance, and rate of work for a total of 54 separate tasks. Carrying heights represented both straight-arm and bent-arm methods of carrying. All tasks except walking were performed at high, medium, and low rates of work. The dependent variable was force for all tasks except walking; for lifting, lowering and carrying tasks, force was adjusted by varying the weight of the object being handled. For pushing and pulling tasks, force was adjusted by varying the resistance against which the force was applied.

During lifting, lowering, and carrying tasks, subjects were required to handle an industrial tote box, 13-1/2 x 19 x 5-1/2 inches with two 7 x 1-5/8 inch handles. A special device was used to automatically lower the tote box after each lift. The device was modified to lift the tote box after each lowering operation. Pushing, pulling, and walking tasks were simulated on a specially constructed treadmill. During walking the treadmill was electrically powered, but during pulling and pushing, it was manually powered by the subject. Strain gauges on the stationary bar measured the horizontal force and acceleration of push and pull. The subject controlled the resistance of the treadmill belt by varying the amount of electric current flowing into a magnetic clutch built into the treadmill.

Twenty-eight males served as subjects and were instructed to adjust their work load to the maximum amount that they could perform without strain or discomfort, and without being tired, weakened, overheated, or out of breath. Three subjects performed simultaneously. Each task was performed for 40 minutes in a controlled environment between 68° and 72°F and 40 percent to 55 percent relative humidity. All subjects wore cotton scrub suits and safety shoes with neolite heels and soles.

RESULTS: Maximum acceptable weights of lift and lower were tabulated. The mean and standard deviation for each task was used to predict the weights that 10 percent, 25 percent, 50 percent, 75 percent, and 90 percent of the male industrial population can be expected to lift and lower.

Two different forces were recorded during pushing and pulling tasks. The force required to get an object in motion is called initial force and is greater than the force required to keep the object in motion, i.e., the sustained force. These forces and work loads for 7-foot push and pull are also tabulated.

Maximum weights and work loads acceptable to subjects when performing carrying tasks are tabulated along with the maximum walking rates selected by the subjects.

217

Snook, et al., 1970 (continued)

RESULTS: (continued)
        There was no significant difference between maximum accept-
able weights of lift and lower. However, work load was signi-
ficantly greater for lowering than lifting. The initial force
for pushing was significantly greater than the initial force
for pulling, but there was no significant difference between
work load and sustained force.
        When carrying the tote box, subjects handled a significantly
greater weight with the straight arm carry than with the bent
arm. The differences among the three replications of walking
task were not significant and the mean walking rates were close
to 3 mph.

SUMMARY: An ergonomic study was conducted to determine man's physical
capacities while performing manual materials handling tasks.
Twenty-eight subjects (industrial) performed three lifting,
three lowering, four pushing, one pulling, one walking, and
six carrying tasks in a controlled environment of 68° to 72°F
and 40 percent to 55 percent R.H. Each task was performed at
three different rates of work. A psychophysical methodology
was used. The subjects controlled their own work load by
adjusting the force variable.
        The results are used to predict the maximum weights and work
loads that are acceptable to different percentages of the male
industrial population.
        This investigation develops data by investigating actual
manual handling tasks and makes an attempt to develop maximum
continuous work capacity criteria with the use of psychophysi-
cal methodology.

CITATIONS: Twelve references.

        Also see: Snook, S.H., Irvine, C.H., and Ross, S.F. Maximum
        weights and work loads acceptable to male industrial workers
        while performing lifting, lowering, pushing, pulling, carry-
        ing, and walking tasks. Paper presented at the American Indus-
        trial Hygiene Conference in Denver, Colorado, May 13, 1969.

218

METHODS: Ten men between the ages of 20 and 23 were selected. The subjects walked for 20 minutes at speeds of 4, 4.8, and 5.6 km/hr in an environment of $22^{o}C$, 50% RH, wearing the standard U.S. Army fatigue uniform (weight 3.5 kg) under each of the following conditions: 1) carrying no load, 2) carrying a load of 4 kg on each hand (total 8 kg), 3) carrying a load of 7 kg on each hand (total 14 kg), 4) carrying a load of 14 kg on the head, and 5) carrying a load of 6 kg on each foot (total 12 kg). The two different hand loads consisted of a pair of boxing gloves wrapped with strip lead. The load on the head consisted of a helmet liner, a steel helmet, and a lead weight brazed in the helmet. The load for the feet was made by filling standard U.S. Army double-walled "vapor-barrier" boots with mercury.

During each of the 20 minute test periods, three 2-minute gas samples were collected using a 350-liter Tissot gasometer; collections were made for minutes 7 and 8, 11 and 12, and 15 and 16. Samples of expired air were analyzed for oxygen and CO_2 with a Beckman E2 paramagnetic oxygen analyzer and a Beckman LB-1 CO_2 analyzer. Resting oxygen consumption and maximum oxygen uptake were determined for each subject.

RESULTS: The total energy cost for each condition was tabulated. With increase in speed, there was an increase in mean total cost of each load.

It was observed that weight may be carried in the hands and on the head without a great increase in energy cost over equivalent body weight increases. However, when the weight is carried on the feet, energy cost is greatly increased; at 4 km/hr the oxygen uptake per kg of weight per minute is about four times that per kg of body weight and clothing. Furthermore, the energy cost for the weight on the feet at the walking speeds of 4.8 and 5.6 km/hr is about six times that per kg of body weight. Each of these energy cost cases is highly significant.

SUMMARY: Ten subjects walked for 20 minutes on a treadmill at 4, 4.8, or 5.6 km/hr carrying: 1) no load, 2) 4 kg on each hand, 3) 7 kg on each hand, 4) 6 kg on each foot, or 5) 14 kg on the head. Energy cost per minute per kg of total weight agreed, for the no load condition, with previous studies. The cost per kg of weight carried on the head was 1.2 times the expected cost per kg of the no load condition at all speeds. At 5.6 km/hr, the cost/kg of load carried in the hands was 1.9 times the no load cost for both 4 and 7 kg loads. It was the same for the 7 kg load at slower speeds also. However it was 1.4 times for the

Soule & Goldman, 1969 (continued)

SUMMARY: (continued)
             4 kg load. The cost/kg of load carried on the feet was 4.2
             times the no load cost per kg at 4 km/hr, 5.8 times at 4.8 km/hr,
             6.3 times at 5.6 km/hr.
               An attempt has been made to study the relative efficiencies
             of the different techniques of carrying load and investigate
             the maximum loads that can be placed in areas such as wrist
             or helmet radios, in spike proof boots, and the relative
             energy costs incurred.

CITATIONS: Fourteen references.

STUDY: Strindberg, & L. Petersson, N.F. Measurement of force percep-
tion in pushing trolleys. Ergonomics, 15(4), 435-438, 1972.

KEYWORDS: Pushing, psychophysical methods, body weight

METHODS: Ten male untrained subjects, between 19-29 years of age were
studied. Their mean height was 184 cm (SD=+6) and mean weight
72 kg (SD=+8). All subjects wore tennis shoes. Three identical
'Post be hallare 69' trolleys measuring 1715 mm (height) X
800 mm (width) X 1200 mm (length) were used and their starting
positions were indicated on the floor (concrete). Three
mechanical dynamometers with different weight ranges were used
for the measurement of required starting force with different
loads. Cardboard containers filled with notepaper and envelopes
were used as load in most cases. Twenty-five kg lead rods
totalling around 300 kg were used for the heavier weights (the
weights varied from 100-800 kg).

The force required to start a trolley rolling was measured
for the 3 trolleys with weight increments of approximately 25
kg.

The maximal pushing ability test was made with an empty
trolley (98 kg) and with a trolley loaded with 700 kg. The
psychophysical method of estimation was used in order to study
the relation between the perceived force and the physical force
needed in pushing trolleys. Seven different weights were used
for the test trolley. The subjects had to estimate the force
necessary to start seven different heavy trolleys and to indi-
cate this force in comparison to the maximal value they thought
themselves capable of exerting in the pushing.

RESULTS: The results verified previous studies in that a person on the
average was able to push a trolley of this type on a horizontal
surface with approximately 80 percent of his body weight.

The perceived force was plotted as a function of the physical
force measured. The three curves for the different trolleys
were in agreement. Up to a force of 130N, perceived force was
about equal to the physical force, but beyond that it increased
more rapidly.

Subject's estimate of the necessary starting force in compari-
son to the maximal value they thought themselves capable of
exerting in pushing increased exponentially. Results were also
used for individual analysis of subject estimation capability
by dividing the median of estimated maximal force by the measured
maximal force. This figure correlated well with subject height,
such that tall persons underestimated their strength and short
persons overestimated it.

SUMMARY: The force perception in pushing trolleys was studied by the
psychophysical method of magnitude estimation, It was found
that forces beyond a certain critical value (130N) were

221

Streindberg & Peterson, 1972 (continued)

SUMMARY: (continued)
experienced as being greater than they actually were. It was
also found that a person on the average can exert a maximal
pushing force expressed in kp which corresponds to approximately
80 percent of his body weight in kg. Tall persons seemed to
underestimate their maximal force and short persons to over-
estimate it.
   This study was an attempt to determine what man himself
regards as an appropriate load and his perception of the vary-
ing degrees of loading involved in trolley handling.

CITATIONS: Four references.

STUDY: Thomas, D.P. The effect of load carriage on normal standings in man. Journal of Anatomy, 93(1), 75-86, 1959.

KEYWORDS: Load carriage, standing posture

METHODS: Ten male students, aged 18-21 years, acted as subjects. Their heights and weights ranged from 170.6 to 188.9 cm and 59.75 to 84.75 kg respectively. Four bony hand marks were marked: 1) the lateral side of the greater tuberosity of the right humerus; 2) the lateral side of the greater tochanter of the femus; 3) the knee joint immediately above the head of the right fibula; and 4) the lateral melleoulus of the right fibula. The subjects stood on a rigid platform with heels 20 cm apart, in a comfortable posture. Each subject was photographed under the following conditions: 1) normal standing, without load; 2) carrying an empty carrier; 3) carrying 12 kg attached to the carrier high on the back; 4) carrying 24 kg as in (3); and 5) carrying 24 kg attached to the carrier low on the back. The load of 24 kg was moved over a distance 30 cm between the 'high' and 'low' positions. For the experiments the subjects wore only trunks and vest. Subjects were photographed twice, but not on the same day, about half a minute after they had been placed in position. This was repeated for each condition and subject. The film negatives were projected on a white screen and measurements were taken directly from it using a grid. The vertical height above the platform, and the horizontal distance from the plumbline were measured for each of the four workers.

The analysis of the results was performed by comparing the positions of the four anatomical markers on each subject under varying load conditions.

RESULTS: The results showed a highly significant forward displacement of the shoulders with loading. The unloaded carrier, however, made no significant difference to the position of any of the markers. The position of the hip marker did not move significantly for the varying load conditions, but the position of the knee marker moved progressively backwards with increasing load carriage. There is, therefore, a highly significant realignment of the body segments with the carriage of loads above a certain minimum weight in the standing position.

There were highly significant differences in position between normal standing and carrying the carrier plus 12 kg, between carrying 12 kg and 24 kg and between carrying 24 kg in the low as compared to the high position. Thus the heavier the load, provided that it exceeded the weight of the carrier (4.25 kg), the further forward the subject leaned, and for the same weight, the lower position on the back caused the shoulder to be displaced further forward.

The position of the shoulder was also compared using the angular displacement from a vertical line through the hip

223

Thomas, 1959 (continued)

RESULTS: (continued)
             marker, but the levels of significance between different
             effects were virtually the same. Similarly the position of
             the hip marker was checked, but it did not change significantly
             with the varying load.
                It was found that the angle between the shoulder-hipline and
             the vertical, and the angle between the ankle-hipline and the
             vertical showed no significant correlation with either the
             weight or the height of the subjects during load carriage.
             There was no evidence that the posture of the subjects when
             loaded was significantly related to their height or weight.
                There was a significant interaction between loads and subjects,
             implying that the effects of the load differ significantly from
             subject to subject.

SUMMARY: The effect of load carriage on the normal standing posture has
             been studied using a miniature camera photographic technique.
             The displacement from the vertical line of marked anatomical
             landmarks was measured on enlarged negative images, during
             normal standing and when loads of 12 and 24 kg were carried.
             It was found that there was a highly significant change in the
             position of the hip. There was a highly significant backward
             displacement of the knee, while the position of the knee was
             not affected.
                It was concluded that a highly significant re-alignment of
             the body position takes place during load carriage above a
             certain minimum weight.
                A weight of 24 kg was found to cause further forward displace-
             ment of the shoulder when it was carried low on the back than
             when it was carried high on the back.
                It is suggested that the trunk acts as a counterbalance,
             altering its inclination according to the position of the load
             on the back, so that the vertical projection of the center of
             gravity remains relatively undisturbed.

CITATIONS: Nine references.

224

STUDY: Tichauer, E.R. A pilot study of the biomechanics of lifting
            in simulated industrial work situations. Journal of Safety
            Research, 3(3), 98-115, 1971.

KEYWORDS: Lifting stress, task severity, lumbar spine, surface myograms,
            force platform, kinesiometer, biomechanical profile of lifting,
            heel height, bulk/weight ratio

METHODS: A system consisting of a force platform (a simplified version
            of Green's model (1957)),a kinesiometer, an oscillographic
            recorder and a fourteen channel analog tape recorder, was con-
            structed to permit the simultaneous analog recording and storage
            of mechanical, biomechanical and myographic data in form of
            biomechanical profile. The profile was representative of the
            magnitude and sequencing of mechanical and physiological events
            associated with a lifting task. The force platform provides
            displacement in absolute terms of the center of mass of the
            body-load aggregate of the subject along the abscissa of the
            mid-sagittal plane, changes in force on the load cell related
            to acceleration of the center of masses of the body-load aggre-
            gate along the ordinate of the mid-sagittal plane,and location of
            the combined center of mass of all of the objects on the plat-
            form at any instant. The kinesiometer provides a continuous
            recording of the location of anatomical landmarks in their
            respective sagittal planes. The following are thus known:
            1. The location in space of the center of mass of the object
            manipulated.
            2. The location in space of the center of mass of the body-load
            aggregate.
            3. By mathematical derivation, the location of the center of
            mass of the human subject.
            4. The distance between the anatomical landmark selected and
            any of the aforementioned centers of mass.
            5. By computational derivation, acceleration at any instant
            of the center of mass of the object handled, of the center of
            mass of the human body-object aggregate, and of the center of
            mass on the human body on the platform.
              Based on the above information, the lifting stress acting at
            any point on an anatomical structure is computed using the
            "moment concept."
              The objects to be manipulated and lifted under experimental
            conditions were boxes, constructed in three different dimen-
            sions, three boxes for each dimension weighing 5, 10 and 15
            pounds, respectively. Thus nine different weight/bulk ratios
            were obtained with only three levels of weight. Load levels
            were determined on the basis of the mean weight of objects
            commonly handled in activities of daily living and in light
            work in industry.
              To validate the moment concept (the rationale was that torque
            to either the lumbar spine or to the hip joint would produce
            stresses in both the sacrospinalis and gluteus maximus muscles),
            a board was constructed holding weights of 5, 10 and 20 pounds,

                                    225

Tichauer, 1971(continued)

METHODS: (continued)
             respectively so as to produce torques on the lumbar spine of
             a magnitude of inch-pounds. Distance from the deepest part of
             the lumbar curvature to the center of mass of the load was 14
             inches, 20 inches, and 26 inches, respectively. These moments
             simualted the effects of weight/bulk ratios.
                A walking experiment was also conducted to bring in the real-
             ism of an industrial situation.

RESULTS: Observations were taken during 60 1-hour tests. It was seen
             that the mean height of the integrated e.m.g. gathered over
             the sacrospinalis muscle is roughly proportional to the moment
             exerted on the lumbar spine rather than to the weight of the
             object held. It was shown that when workers are mobile, the
             surface myograms of glutaeus maximus and sacrospinalis muscles
             are reliable indices of the moment exerted on both lumbar
             spine as well as on the hip joint. The increase in moment
             while the weight remained constant demonstrates that the nature
             of task changes from high to medium heavy. This proves that
             weight considered alone is meaningless as an indicator of the
             severity of a lifting task, but that torque is the true index.
                It was concluded that the surface myogram over glutaeus maximus
             could be developed into an acceptable indicator of biomechanical
             stress on the lumbar spine during walking. A good correlation
             between the walking speed and the mean height of the surface
             myogram was also found.
                Also, biomechanical lifting profiles were obtained from two
             different lifting techniques. It was observed that minor varia-
             tions in heel height of shoes affected the sacrolumbar angle
             and also altered the general lordatic configuration of the verte-
             bral column during lifting. It was concluded that heel height
             as well as lumbo-sacral angle are major factors influencing the
             magnitude of any biomechanical bending moment acting on the
             lumbar spine and thus may vary substantially the severity of a
             lifting task, even if the load does not change. This is
             more significant in women than in men.

SUMMARY: A methodology for the application of kinesiometry to lifting and   ·
             materials handling situations was theoretically validated and
             confirmed by practical "spot testing". Two kinesiometers and a
             force platform were constructed for the experimentation. It was
             established that the weight/bulk ratio of the object handled is
             a major determinant of the severity of a lifting task and this
             together with lifting technique determines the bending moment
             acting on the vertebral column. It was found that even minor
             variations in the heel height of the working shoes affect the
             lordosis of the vertebral column, and the same was true for minor
             changes in posture due to lifting techniques. It was shown that
             lifting techniques which increased the sagittal bending moment
             on the lumbar spine, produced large myoelectric responses from
             the glutaeus maximi. Also, any increase in sagittal bending moment

Tichauer, 1971 (continued)

SUMMARY: (continued)
              increased the time necessary to lift and reduced the pace when
              walking with the object in hand.
                 It was shown that weight limitations on lifting are valueless
              and irrelevant because they do not consider weight/back ratio
              of the object handled, nor do they consider the protection of
              individuals with pre-existing impairment.
                 The results of this study provide a basis for developing
              quantitative relationships between weight/bulk ratio and work
              tolerance. Also important is the development, in many classes
              of back injuries, of satisfactory methods of rehabilitative
              treatment which would enable the patient to successfully handle
              work situations within a normal environment and without further
              impairment to his health. The results can be applied to explore
              the possibility of developing rules and revision of legislation
              to protect rehabilitees from further disability resulting from
              poorly designed work situations.

CITATIONS: Forty-nine references.

METHODS: Ten women served as subjects to determine whether a causal relationship between spinal curvature and the loads lifted could be established. The supposition was made that via the mapping techniques of the spinal curvature, both the magnitude and location of the spinal response to lifting stress could be defined. The variables examined were subject body type, weight of load, and bulk/weight ratio of the load. The subjects, classified as either ectomorphic or endomorphic, were required to hold boxes of several sizes (i.e., small and large) and weights (i.e., 5 lbs, 10 lbs., 15 lbs.) for durations of time ranging from two minutes to ten minutes. A stylus of the lordosimeter mapped the spinal curvature while the loads were held.

RESULTS: The processed data revealed substantial variations in the measured parameters. It is conjectured that each subject can assume a nearly infinite number of postural configurations when standing at rest, provided that stable balance is maintained. Changes in lumbosacral angle and slope of the line of best fit were determined for all subjects holding large and small boxes of the three weight levels and the two time intervals. The deliberate choice of packages of similar weights but different bulk was intended to assess the significance in lifting tasks of bulk/weight ratio as well as weight alone. However, no direct relationship could be developed between spinal response and weight alone. Lordotic response to each weight level was affected by the box size.

    In the no-load condition, the average lumbosacral angle is close to 180 degrees, and the range of its variation is less for the ectomorphs. Lumbosacral adjustments of the lowest movement (lightest small package) occur randomly for both body types, but with a narrower range for the ectomorphs. Generally, in reaction to light load application, ectomorphs tend to arch, and endomorphs tend to straighten. At greater levels of loading, the ectomorphs tend to arch consistently, but the endomorphs respond randomly by either arching or straightening. Changes in slope of the best fit are negative for both groups of two and ten minute durations. The variation of slope is greater for endomorphs, making their trends more random than the ectomorphs.

228

Tichauer, et al., 1973 (continued)

RESULTS: (continued)
         The range of ectomorphic arching at two minutes is sub-
stantially reduced at ten minutes. Endomorphs, however, do
not show different behavioral patterns of lumbosacral adjust-
ment in time.
         It was found that subjects were unable to hold the heavier
large box for the assigned ten minute term, although weights
of ten or fifteen lbs. are not considered severe by current
lifting standards.
         The large load produced effects markedly different from
the small load. At the two minute interval, the ectomorphs
showed reduced range of adjustment for the lower range of
movements; as the moments increased so did the range of adjust-
ments. The endomorphs showed a random variation in arching
at the low range of moments for the two and ten minute tasks.
In the high range, the response became more uniform for the
endomorphs. For all subjects, body tilt adjustments were
positive with the large box. For the long duration task with
the heaviest load, all subjects showed the broadest spread of
lumbosacral adjustments.
         At the critical task level with incipient failure, the
subjects maintained balance with large excursions in random
directions.

SUMMARY: The objective of this pilot study is to determine whether
through lordosimetry a quantifiable causal relationship can
be found between spinal curvature changes and the loads that
cause them.
         A device was designed and constructed which maps the config-
uration of the vertebral column. It was used to record changes
in spinal configuration and general posture of a group of female
subjects engaged in the holding of loads of different weights
and bulk/weight ratios. This new apparatus provides a poten-
tially useful procedure of the simple measurement of postural
reaction to physical work stress during manual materials handling
in industrial practice.
         In the course of the study, measurements and procedures
were standardized; the effects of body type, load bulk, and
load weight on postural reaction were discussed.

CITATIONS: Eighteen references.

STUDY: Tichauer, E.R., Yagoda, H.P., Weinstein, J.M. & Wall, R.A.
             Design criteria for packages and containers: A report on the
             state of the art, submitted to NIOSH, Cincinnati, Ohio, October
             15, 1972.

KEYWORDS: Manual materials handling, design criteria, loads, exertion,
             containers

METHODS: The report evaluates research needs for the development of
             criteria for recommended standards for the design of packages
             and containers, i.e., for size, shape, weight and labeling
             of packages or containers to reduce all kinds of resulting
             injuries. An attempt has been made to review pertinent litera-
             ture, determine gaps in research, and make recommendations of
             actions necessary to fill such research gaps.

RESULTS: The findings of Tichauer and his associates include information
             procured from a literature search as well as from information
             obtained from international organizations and government organi-
             zations. Research was conducted by biomechanical techniques
             into the physical response of the back as well as other struc-
             tures of the body in the efforts required by manual-materials
             handling. Recommendations are offered concerning the marking
             of containers, regarding standards development, and regarding
             identification of organizations with capabilities in ergonomics
             and biomechanics.

SUMMARY: Finally, it must be stated that all research results currently
             available in the U.S.A. concern themselves with "lifting" per
             se and not with the relevance of container design and container
             handling methods in the maintenance of occupational safety and
             health.
                There is not sufficient data available for the formulation of
             reliable standards as related to container design, labeling,
             and handling. Loosely formulated standards would not protect
             the working population, would be unenforceable, and could lead
             to alienation between governmental agencies, labor, and manage-
             ment. It is, therefore, necessary to proceed along the slower,
             but both in the long run as well as in the short run, more
             fruitful avenue of purposeful and accelerated research in this
             field and to produce draft standards as soon as the information
             to support them becomes available.

CITATIONS: Twenty-five references.

STUDY: Troup, J. D. C. Relation of lumbar spine disorders to heavy
             manual work and lifting. Lancet, 857-861, April 17, 1965.

KEYWORDS: Lifting, lumbar spine disorders, biomechanics

METHODS: Troup's paper is concerned with low-back disorders which are
             among the major causes of absenteeism in industry and account
             for much disability both in industry and at home. Troup discusses
             the prevalence of back injuries, their etiology, significance
             of x-ray changes, the biomechanics of lifting, pathological
             changes, lifting regulation, and training programs.

RESULTS: The paper points out that the data on the extent of the low-
             back problem, though incomplete, indicate that, considered to-
             gether, these disorders form a massive group and that the cost
             in terms of sickness and injury benefits, the charge on the
             National Health Service, and loss of productivity and earnings is
             enormous. The paper also discusses the signifigance of x-ray
             screening of workers as a valid procedure pointing out that it
             is not always a good method. The author then compares the two
             methods of lifting (stooping and squating) showing that without
             adequate physical training, the flexed knee or "kinetic" lift
             is not necessarily the safest method. Also, he indicates that
             in lifting the greatest stresses arise at the beginning of
             the lift-together with an increase in intra-abdomnial pressures.
             He stresses the importance of training in lifting.

SUMMARY: The data on the extent of the low-back problem, though incom-
             plete, indicate that, considered together, these disorders form
             a massive group. Unfortunately, none of the figures on back
             injuries and manual handling accidents are comparable. The
             way in which the necessary information is collected and analyzed
             is not adaptable enough to provide the required information.
             For instance, back-injury rate in different industries cannot
             be compared. because of varying efficiency in reporting accidents.
                A move toward standardization in reporting accidents is
             apparent, based on the incidence of accidents causing "three
             day plus" incapacity. This is logical and such a process
             is essential for purposes of comparison, but in relation to
             back injuries, it tends to exclude useful information, since the
             spine can be irreversibly damaged without necessarily causing
             immediate incapacity. Information on the incidence of both
             trivial and serious injuries is therefore equally valuable.
             With more efficient reporting, the frequency with which particular
             tasks are associated with back injuries can be correlated with
             the relative frequency with which each task is performed in the
             course of a day's work. In this way the relative dangers can
             be assessed.
                Unfortunately, knowledge of the physiology of lifting and
             similar heavy work is in its infancy. The stresses produced
             in the spine during actual maneuvers, the mechanics of the
             movement involved, and the forces exerted, have only recently
             been given attention, and so far for only a limited number of
             tasks. But investigations of this kind are essential before

Troup, 1965 (continued)

SUMMARY: (continued)
             dangers inherent in some types of manual work can be properly
             understood and the safest methods for performing them can be
             devised. The selections of manual tasks for analysis must
             wait until more is known of the epidemiology of low-back
             disorders.

CITATIONS: One reference.

Troup, 1965 (continued)

SUMMARY: (continued)
            dangers inherent in some types of manual work can be properly
            understood and the safest methods for performing them can be
            devised. The selections of manual tasks for analysis must
            wait until more is known of the <u>epidemology</u> of low-back
            disorders.

CITATIONS: One reference.

STUDY: Troup, J.D.C. & Chapman, A.E.   The strength of the flexor and
           extensor muscles of the trunk.   Journal of Biomechanics, 2,
           49-62, 1969.

KEYWORDS: Maximal push and pull, turning moment of the trunk, dynamic
           strength, hip flexion/extension

METHODS: A. Measurements of static strength
           The maximal forces exerted while pushing and pulling were
           measured using a special apparatus which was designed so that
           subjects applied forces manually, their upper limbs horizontal,
           with their trunks vertical and their pelvis held firmly between
           anterior and posterior padded bars. Forces were measured in
           two postures: standing and sitting. The apparatus could be
           adjusted to suit the dimensions of the subject. Subjects were
           asked first to exert a submaximal force to accustom themselves
           to the apparatus, keeping elbows and knees extended. The two
           maximal exertions were made, subjects being asked to hold the
           maximum for about 1 second. The results were recorded to the
           nearest kg. Taking into account the time of response of the
           galvanometer, the duration of the exertion was 3 to 4 seconds.
           B. Measurement of the ability to flex and extend the trunk
               while overcoming the effect of gravity
           The ability to achieve and hold postures at the extremes of
           the range of flexion and extension of the trunk and hips was
           measured in two tests: sit and reach, inclined and prone trunk
           raising. They were tests of dynamic strength only in as much
           as movement was required of the subject in performing them.
           C. Measurements of mobility
           The ranges of sagittal movement of the lumbar spine and hips
           were estimated from observations made on subjects in fully
           flexed and fully extended postures. Lumbar movement was cal-
           culated indirectly by estimating the range of movement between
           the thoracic lumbar region and the femora and subtracting from
           it the range of movement at the hip joints.
           D. Anthropometric measurements
           The following were measured: weight, to the nearest kg; sta-
           ture, to the nearest cm; trochanter height; sitting height and
           reach height.

RESULTS: A. Measurement of static strength
           The forces exerted by the males were significantly greater
           than those exerted by the females, both in absolute terms and
           when expressed as a proportion of the body weights of the two
           sexes. Flexor forces were consistently less in magnitude than
           extensor forces and flexor turning moments were similarly less
           than extensor turning moments. The flexor forces exerted were
           somewhat greater standing than sitting, but with the difference
           in handle/bar heights in the two postures, the flexor turning
           moments were greater in the standing position. The converse
           applied to the extensor forces and moments, the latter being
           similar in the two postures.

233

Troup & Chapman, 1969 (continued)

RESULTS: (continued)
B. <u>Sit and reach, inclined test</u>
1. The mean distances between fingertips and the plantar surface of the feet achieved in the performance of this test were closely similar in the two sexes.
2. Prone, trunk raising: The mean vertical distances moved at C7 in the performance of prone, trunk raising were 35.6 cm for both sexes. When the mean scores were expressed as a proportion of the mean sitting height, the ratios were .57 and .53 for females and males respectively.
C. <u>The relationships between variables</u>
All the forces and all the turning moments in the static tests of strength correlated significantly with each other for both sexes. Flexor forces correlated as well with each other as with extensor forces, and the same applied to flexor and extensor moments. Forces and moments correlated well with each other also, particularly those concerning the same maneuver. The sit and reach, inclined (S.R.I.) and prone trunk raising (P.T.R.) tests of strength correlated significantly with each other in the male subjects (p<.01) but not in the females.

The individual measurements of static strength were significantly related to subjects' weight, particularly with the male subjects. But there was no significant association between weight and either the S.R.I. or the P.T.R. tests.

The relationship between the range of sagittal movement of the hips and the static tests of strength was of no significance although there were three exceptions in male subjects in whom there were negative correlations at comparatively low levels of significance. On the other hand the degrees of lumbar flexion/extension correlated significantly in both sexes with the flexor forces and moments in the seated position and with extensor forces and moments standing in the females. Hip flexion/extension correlated significantly with both the S.R.I. and the P.T.R. tests particularly with the males; and in both sexes, lumbar flexion/extension was significantly associated (p<.001) with the S.R.I. and P.T.R. tests of strength.

SUMMARY: Disorders of the lumbar spine are widespread in industrial communities, and the amount of incapacity they cause is considerable. There is thus a need for objective methods of assessing individual capacity for work involving the spine and trunk. This investigation was planned to provide data on the flexor and extensor turning moments on the trunk during maximal static contractions in two postures, standing and sitting. The tests were devised to measure subjects' ability to maintain postures at the extremes of flexion and extension while overcoming the effect of gravity on the trunk. In addition the

234

Troup & Chapman, 1969 (continued)

SUMMARY: (continued)
ranges of sagittal movements of the lumbar spine and hips were
measured together with subject's weight, stature, sitting
height, and the lengths of their upper and lower limbs.

CITATIONS: Forty references.

STUDY: Whitney, R.J. The strength of the lifting action in man. Ergonomics, 1(2), 101-128, 1958.

KEYWORDS: Strength, type of lifting, foot placement, type of grasp

METHODS: The strength of the lifting action was measured under the following defined conditions:
1. The subject was instructed to exert a steady, maximum lifting force on a horizontal bar placed in a frontal plane. The duration of the steady force was three seconds.
2. The bar was of circular cross section, 3.2 cm diameter and the span of the two-handed symmetrical grasp was maintained at 40 cm throughout.
3. Subjects were instructed to employ a closed grasp throughout, and both overhand and underhand grasps were investigated.
4. Three grasp heights were investigated, viz. 12.5, 25.0, and 50.0 cm above ground level.
5. Foot stance was maintained at 20 cm throughout.
6. Foot placement was investigated at three distances of heel contours from the frontal plane, viz. 30, 40, and 50 cm.
7. In each lifting effort the subject was instructed to adopt one of two types of lifting action - either derrick (stooping) or knee action (squat).

The apparatus consisted of a force platform and recording equipment. The subjects employed in these experiments were male student volunteers between the ages of 18 and 20 years. Eight subjects, of statures from 172.6 to 192.3 cm and of body weights from 63.9 to 84.0 kg, were investigated. For the lifting experiments all subjects wore shorts, singlet, thin socks and rubber-soled plimsolls. The routine of the experiments was designed to randomize with time the variables of the experiment as far as practical. Each subject completed the whole set of lifting actions over three separate days. On each experimental day the subject performed six separate "blocks" of lifting actions at one grasp height and two further blocks of actions at another grasp height. The six blocks of actions included all combinations of foot placement, grasp (overhand or underhand) and lifting action (derrick or knee) at the one grasp height.

RESULTS: 1. The most important variable determining the maximum lifting force was the distance of the feet from the frontal plane including the grasp axis. The force decreases rapidly with increase of this distance.
2. The maximum lifting force also decreased with increase of grasp height, but the influence of grasp height was much less than that of foot placement distance.
3. None of the other variables considered, apart from subject-to-subject variation, had an appreciable effect on the maximum lifting force, in particular lifting actions.

Whitney, 1958 (continued)

RESULTS: (continued)
             4. In all lifting operations the turning moment exerted on the
                 body by the lifting effort has to be counterbalanced by an
                 opposing moment produced by the body weight. It was sug-
                 gested that in most practical lifting operations the maxi-
                 mum lifting force is limited by the maximum counterbalancing
                 moment which the body weight can provide, and that only
                 exceptionally with the inherent muscular strength of body
                 extension being the limiting factor. This appeared to be
                 the chief reason why the heavier subject could exert a
                 greater maximum lifting force under specified conditions.

SUMMARY: The maximum isometric force exertable on a horizontal bar
             situated in a frontal plane was found to vary, for either young
             male subjects and for the different lifting conditions observed,
             from 15 to 120 kg. Increase of foot placement distance from
             30 cm to 50 cm effected the largest reduction in lifting force.
             The reduction produced by increase of grasp height from 12.5 cm
             to 50 cm was very much less,and the effect of type of grasp
             (overhand or underhand) and type of lifting action (using or
             not using knee extension) was generally small. It appeared
             that the magnitude of the lifting force was largely determined
             by the magnitude of the force moment which the body mass could
             exert to counterbalance the reaction of the lifting force upon
             the body.

CITATIONS: Twenty-six references.